A tall, slender metal windmill stands in a vast, arid desert landscape. The windmill has a spiral of metal blades at the top and a sign that reads "THE ALBERTA MOTOR". A person in a red shirt and blue shorts stands at the base of the windmill, providing a sense of scale. In the background, a white car is parked near a small building, and distant mountains are visible under a clear blue sky.

Ambient Groundwater Quality of the Sacramento Valley Basin: A 1999 Baseline Study

ADEQ Open File Report 01-04
June 2001



Ambient Groundwater Quality of the Sacramento Valley Basin: A 1999 Baseline Study

**By Douglas C. Towne and Maureen C. Freark
Maps by Larry W. Stephenson**

Arizona Department of Environmental Quality Open File Report 2001-04

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Report Cover: ADEQ staff pose for a photo after sampling a windmill which supplies water to a tank and trough for stock use. This site is located in a remote area on the western flank of the Hualapai Mountains. Across Sacramento Valley, the Black Mountains are also visible (Photo by Douglas Towne).

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

Ambient Groundwater Quality of the Willcox Basin: A 1999 Baseline Study. ADEQ Publication OFR 01-09, October 2001, 66 p.

Ambient Groundwater Quality of the Willcox Basin: A 1999 Baseline Study. ADEQ Publication FS 01-13, October 2001, 4 p.

Ambient Groundwater Quality of the Sacramento Valley Basin: A 1999 Baseline Study. ADEQ Publication FS 01-10, June 2001, 4 p.

Ambient Groundwater Quality of the Yuma Basin: A 1995 Baseline Study. ADEQ Publication FS 01-03, April 2001, 4 p.

Ambient Groundwater Quality of the Virgin River Basin: A 1997 Baseline Study. ADEQ Publication FS 01-02, March 2001, 4 p.

Ambient Groundwater Quality of the Prescott Active Management Area: A 1997-98 Baseline Study. ADEQ Publication FS 00-13, December 2000, 4 p..

Ground-Water Quality in the Upper Santa Cruz Basin, Arizona, 1998. Joint Publication: USGS Water Resources Investigations Report 00-4117 - ADEQ Publication OFR 00-06, September 2000, 55 p.

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Ambient Groundwater Quality of the Prescott Active Management Area: A 1997-98 Baseline Study. ADEQ Publication OFR 00-01, May, 2000, 77 p.

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Ambient Groundwater Quality of the Virgin River Basin: A 1997 Baseline Study. ADEQ Publication OFR 99-4, March 1999, 98 p.

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The Impacts of Septic Systems on Water Quality of Shallow Perched Aquifers: A Case Study of Fort Valley, Arizona. ADEQ Publication OFR 97-7, February 1997, 70 p.

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<http://www.adeq.state.az.us/environ/water/assess/target.html#studies>

ABBREVIATIONS

af	acre-feet
af/yr	acre-feet per year
AMA	Active Management Area
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADWR	Arizona Department of Water Resources
bls	below land surface
BLM	Bureau of Land Management
CI _{0.95}	95 percent Confidence Interval
dD	stable isotope of hydrogen
d ¹⁵ N	stable isotope of nitrogen
d ¹⁸ O	stable isotope of oxygen
GMWL	Global Meteoric Water Line
gpm	gallons per minute
INS	Insufficient nitrogen for isotope analysis
LLD	Lower Limit of Detection
MCL	Maximum Contaminant Level
msl	mean sea level
Fg/l	micrograms per liter
FS/cm	microsiemens per centimeter at 25E Celsius
mg/l	milligrams per liter
MRL	Minimum Reporting Level
MTBE	Methyl tertiary-butyl Ether
ntu	nephelometric turbidity unit
ND	Not detected above the minimum reporting level
pCi/l	picocuries per liter
PWS	Public Water System
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
SDW	Safe Drinking Water
SV	Sacramento Valley
SVGB	Sacramento Valley Groundwater Basin
SC	Specific Conductivity
su	standard pH units
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound

“For whatever else groundwater hydrology may be, it is certainly a spatial science.”

Douglas McCarty
ADEQ Hydrologist

*An Application of Geomatic Methods and Global Positioning System Error Analysis
to the Mapping of Water Table Surfaces*

Ambient Groundwater Quality of the Sacramento Valley Basin: A 1999 Baseline Study

By Douglas C. Towne and Maureen C. Freark

Abstract

A regional groundwater quality study of the Sacramento Valley groundwater basin (SVGB) was conducted by the Arizona Department of Environmental Quality (ADEQ) to determine the suitability of groundwater for drinking water purposes, appraise current (1999) baseline conditions, and examine spatial groundwater quality patterns. The SVGB is located in Mohave County in northwestern Arizona. Groundwater is the main water source in this semiarid basin. Sampling was conducted at 48 sites: 40 random sites and 8 targeted sites. Groundwater samples were collected for Safe Drinking Water (SDW) inorganics, SDW Volatile Organic Compounds (VOCs), perchlorate, and isotopes of hydrogen, oxygen, and nitrogen. At 40 sites, samples were collected for SDW radiochemistry analysis.

Interpretation of results from laboratory analyses of collected groundwater samples indicate that 20 of the 48 sites met all U.S. Environmental Protection Agency (USEPA) drinking water quality standards (41). USEPA health-based water quality standards, termed Primary Maximum Contaminant Levels (MCLs), were exceeded at 22 of 48 sites. Primary MCL exceedances included gross alpha (18 sites), nitrate (6 sites), fluoride (4 sites), radium-226+228 (4 sites), and antimony (2 sites). In addition, 17 sites exceeded the proposed Primary MCL for uranium. USEPA aesthetics-based water quality guidelines, termed Secondary MCLs, were exceeded at 28 of 48 sites. Water with Secondary MCL guidelines may be unpleasant to drink, but it is not considered to be a health concern (41). Secondary MCL guidelines included total dissolved solids (TDS) (24 sites), fluoride (16 sites), chloride (7 sites), sulfate (7 sites), manganese (3 sites), and iron (2 sites). Arizona aquifer standards had exceedances that were identical to Primary MCL exceedances (3). No VOCs, including methyl tertiary-butyl Ether (MTBE), were detected at any site. Perchlorate, a man-made inorganic salt used in the manufacture of explosives and very mobile in groundwater, was detected at four sites.

Despite these numerous water quality exceedances many of the SVGB groundwater sites, including those in the central valley and in the Black Mountains in the western basin periphery, meet drinking water standards. Water quality standard exceedances were identified in three principal basin areas.

- < In the vicinity of the town of Chloride, exceedances of gross alpha, radium-226+228, TDS, nitrate, chloride, antimony, sulfate, and manganese occurred. These exceedances appear to be due to a combination of the area's granitic geology, historic mining activity, and septic systems (32).
- < In the central and southern Hualapai Mountains, exceedances of gross alpha, radium-226+228, fluoride, TDS, chloride, and sulfate occurred. The radiochemistry exceedances appear to be related to the area's granitic geology (22).
- < In the vicinity of the town of Topock, exceedances of fluoride, TDS, and chloride occurred. These exceedances appear to be due to dissolution reactions that increase constituent concentrations as groundwater migrates downgradient within the basin (29).

Groundwater in the basin is generally *slightly alkaline, hard to very hard*, and *fresh* based upon pH, hardness, and TDS levels (13)(18). Half of the 48 sites had a calcium-bicarbonate chemistry which is typical of recharge areas in Arizona (29). Sixteen sites had a calcium-sulfate chemistry, six samples had a sodium-bicarbonate chemistry, and the two most downgradient sites had a sodium-sulfate chemistry. Nitrate concentrations at 20 sites were greater than 3.0 mg/l (as nitrogen) which may indicate impacts from human activities (23). Trace elements such as aluminum, antimony, barium, beryllium, cadmium, iron, lead, manganese, mercury, silver, and thallium were rarely detected; only arsenic, boron, chromium, copper, fluoride, selenium, and zinc were detected at more than 10 percent of the sites.

Data from randomly-selected sample sites examined using various statistical methods found groundwater quality constituents varied by aquifer, geology, geographic location, and with groundwater depth. The following significant ($p \leq 0.05$) trends were observed. Concentrations of many constituents were higher in the hardrock aquifer compared to the alluvial aquifer, a pattern similar to that found in other Arizona groundwater basins (29)(37)(38). Additional patterns were revealed when the hardrock aquifer was further subdivided into granitic, metamorphic, volcanic, and sedimentary rocks. Groundwater associated with granitic rock frequently had higher constituent concentrations than groundwater associated with volcanic rock and alluvial fill. These findings support previous studies in the SVGB that found more mineralized groundwater in or near mountain areas compared to the central valley (15)(27). Groundwater movement in the basin is from north to south. A chemical flowpath evolution was observed along this flowpath. Concentrations of constituents such as calcium, magnesium, bicarbonate, and hardness tend to decrease downgradient while sodium, chloride, fluoride, and boron tend to increase. Statistical tests support these observations. Concentrations of sodium and some trace elements were higher in the southern, downgradient portion of the basin than in the upgradient northern portion. These constituents probably are increasing due to dissolution reactions (29). In addition, a positive correlation existed among levels of calcium, magnesium, bicarbonate, sulfate, and hardness. In contrast, a positive correlation existed among levels of sodium, chloride, sulfate, boron, and fluoride. Many constituent concentrations tend to decrease significantly ($p \leq 0.05$) with groundwater depth below land surface (bls) though parameters such as pH and temperature increased with increasing groundwater depth bls. A *critical level*, ranging between 50 and 200 feet bls, was established for many constituent concentrations. At groundwater depths greater than the *critical level*, concentrations remain generally constant; in contrast, concentrations are highly variable at more shallow depths. A groundwater quality time-trend analysis was conducted utilizing data collected by the U.S. Geological Survey in 1979, the Arizona Department of Water Resources in 1990, and ADEQ in 1999. Constituent concentrations were largely found to be stable over a period stretching up to 20 years. This suggests that constituents are largely controlled by natural factors and are not prone to vary significantly over time.

This study is the first application of stable isotopes in characterizing regional groundwater by ADEQ and was partially intended to test the usefulness of this technology. Based upon deuterium and oxygen isotope data, groundwater in the basin appears to have undergone a consequential amount of evaporation prior to recharge which is characteristic of arid regions. Future sampling for these two isotopes appears to be of greatest value for regional studies in basins having a major perennial river and where there is a need to distinguish water recently recharged from river infiltration and paleo-water representing a non-renewable resource. In contrast, there appears to be fewer potential uses for regional nitrogen isotope sampling. Data interpretation for this study suggests that it is not possible to determine the source of nitrate groundwater contamination simply by measuring nitrogen isotopes without sampling sites which specifically measure the nitrogen isotope signature of each potential source of nitrogen.

INTRODUCTION

The Sacramento Valley groundwater basin (SVGB) (**Figure 1**) covers approximately 1,500 square miles in northwestern Arizona (27). This basin is located within the political boundaries of Mohave County and the natural boundaries of the Basin and Range lowlands province. Groundwater is the primary source for municipal, domestic, mining, livestock, and irrigation uses in the basin. Recent growth in the SVGB, as evidenced by the 35 percent population increase in the city of Kingman between 1990 and 1997, will likely cause increased demands upon groundwater resources and may affect their quality (2).

Purpose and Scope

The importance of groundwater quality has become increasingly recognized with the expansion of groundwater development, resulting in the Arizona Department of Environmental Quality (ADEQ) conducting a regional groundwater quality study in the SVGB. Sampling by ADEQ was completed as part of the Ambient Groundwater Monitoring Program, which is based on the legislative mandate in the Arizona Revised Statutes §49-225 (3) that authorizes:

“...ongoing monitoring waters of the state, including...aquifers to detect the presence of new and existing pollutants, determine compliance with applicable water quality standards, determine the effectiveness of best management practices, evaluate the effects of pollutants on public health or the environment, and determine water quality trends.”

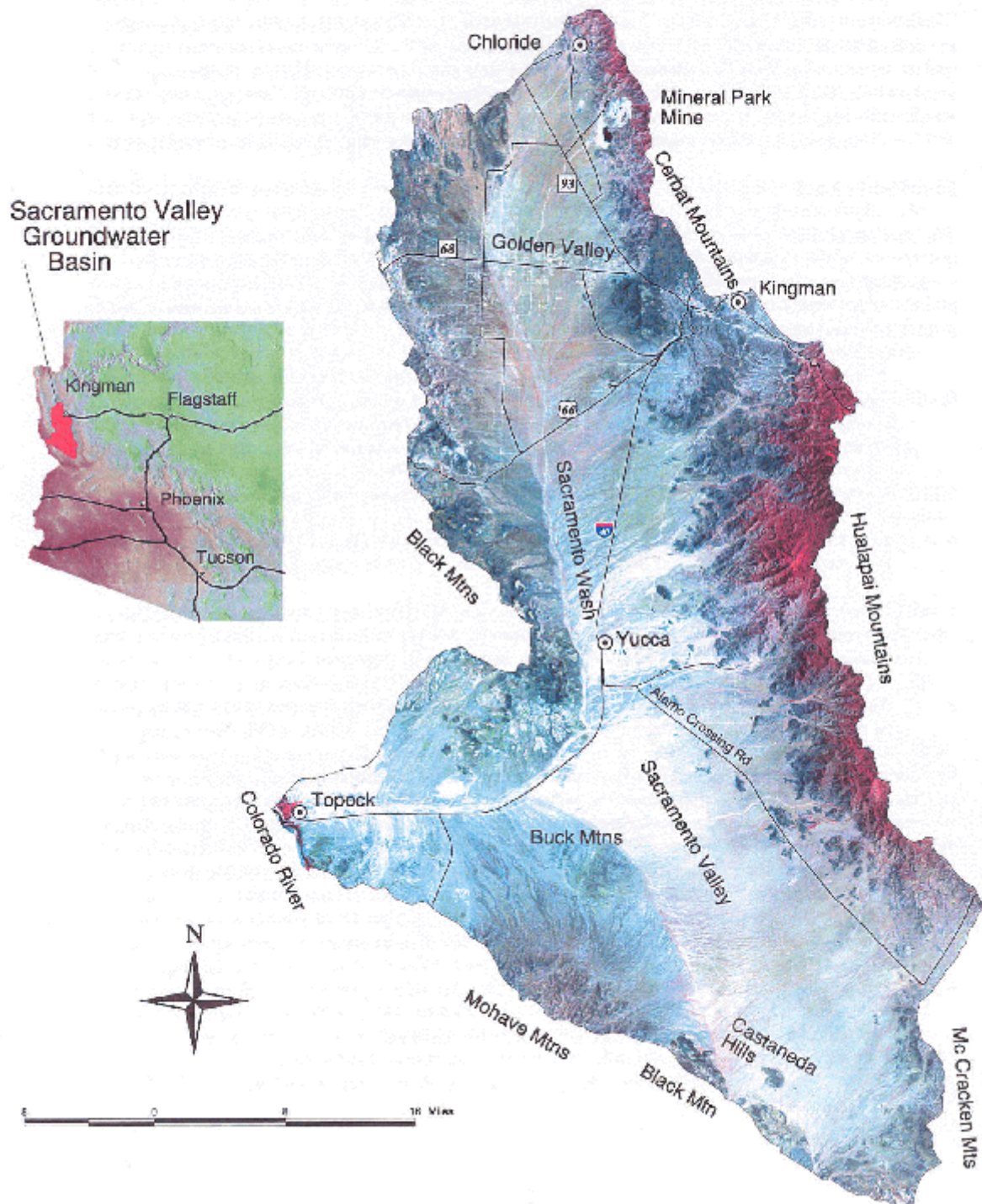
The following factors also influenced the selection of Sacramento Valley for a basin study:

- < Only a limited amount of groundwater quality information has been collected within its boundaries (21)(33).
- < Recent population growth and an associated increase in the number of wells has provided this opportunity to collect groundwater samples from portions of the basin not previously investigated.
- < This groundwater quality study would support the hydrologic analysis requirements and missions of the ADEQ Watershed Program, the ADEQ Northern Regional Office, and Mohave County.

The current SVGB assessment examined regional groundwater quality. Water quality samples were collected and analyzed for 48 sites consisting of either wells or springs. This assessment reports the concentrations of potential groundwater quality constituents including physical parameters, major ions, nutrient constituents, trace elements, volatile organic compounds (VOCs), perchlorate, radionuclides, and isotopes of hydrogen, nitrogen, and oxygen. SVGB groundwater quality concerns discussed in this report include the following:

- < Suitability of groundwater for domestic or municipal uses.
- < Current (1999) baseline groundwater quality conditions.
- < Significant spatial and temporal groundwater-quality patterns.

Figure 1 - Sacramento Valley Groundwater Basin



This report is composed of statistical analyses of water quality data to support groundwater quality conclusions. The results from this study can be used for the following benefits:

- < A methodology for estimating groundwater quality conditions on a regional scale to identify geographical areas characterized by impaired groundwater quality. Residents utilizing water supplied by a public system for domestic purposes could have assurances that their water is regularly tested and meets water quality standards required by the Safe Drinking Water (SDW) Act. Many rural Sacramento Valley residents are served by private wells which are seldom tested for constituents which could have adverse health effects. Arizona statutes only require well drilling contractors to disinfect new wells used for human consumption for potential bacteria contamination. Collecting and analyzing groundwater samples from each private well within the basin would be prohibitively expensive. An affordable alternative is the development of a statistically-based study to describe regional groundwater quality conditions.
- < A process for evaluating potential groundwater quality impacts attributable to specific sources such as natural mineralization, mining, agriculture, septic tanks, and improper well construction.
- < A process for evaluating the effectiveness of groundwater protection efforts such as aquifer protection permits and Best Management Practices by tracking groundwater quality changes.
- < A process to assist in identifying suitable locations for new public water supply wells and aid city and town planners in guiding urban development.
- < A process for providing reliable information on the status and trends of groundwater resources.

Physical Setting

The SVGB, an intermontane, alluvial-fill basin located in northwestern Arizona, is similar in physical structure to the other groundwater basins located within the Basin and Range lowlands province. These basins, formed by fault block mountain ranges, generally trend northwest-southeast (29). The mountains which comprising the boundaries of the SVGB, and their compositions, are noted below (**Figure 1**)(15):

- < **Cerbat Mountains** - form the northeast border of the SVGB and are composed mainly of Precambrian igneous and metamorphic rocks such as granite, gneiss and schist.
- < **Hualapai Mountains** - form the eastern border of the SVGB and are composed mainly of Precambrian igneous and metamorphic rocks such as granite, gneiss and schist.
- < **Mohave & McCracken Mountains** - form the southern border of the SVGB and are composed of Precambrian gneiss and Cretaceous volcanics.
- < **Black Mountains** - form the western border of the SVGB and are composed mainly of Cretaceous, Tertiary, and Quaternary volcanics.

The northern boundary of the basin is formed by bajadas which act as a partial divide between the Sacramento Valley and Detrital Valley groundwater basins. The average elevation of the SVGB is 2,500 feet above mean sea level (msl). Elevations range from a high of 8,417 feet above msl in the Hualapai Mountains to a low of approximately 500 feet above msl near the town of Topock at the Colorado River.

The floor of Sacramento Valley gently slopes southward from approximately 3,500 feet above msl at its north end near Chloride to about 500 feet above msl at the south end near Topock (15). The climate within this basin is semiarid and characterized by high evaporation rates, high summer temperatures, and small amounts of precipitation (15). Annual precipitation in the basin increases with altitude. Rainfall averages 4 inches near Topock, 10 inches at the city of Kingman, and more than 20 inches atop Hualapai Peak (27). Precipitation occurs mainly during the winter as a result of storms moving inland from the Pacific Ocean. Summer storms occur from warm moist air from the Gulf of Mexico (15).

The lower elevations of the basin are classified as a Mohave Desert scrub ecosystem characterized by several varieties of cactus, yucca, Joshua trees, and desert shrubs including creosote bush, desert holly, white burro brush, black brush, mesquite, crucifixion thorn, and ocotillo. At the higher elevations, juniper, pinon pine, and scrub oak predominate. Ponderosa pine is abundant above 6,500 feet (15). Of particular botanical interest is the presence of the saguaro cactus along the western foothills of the Hualapai Mountains, the northernmost natural habitat of this species (41).

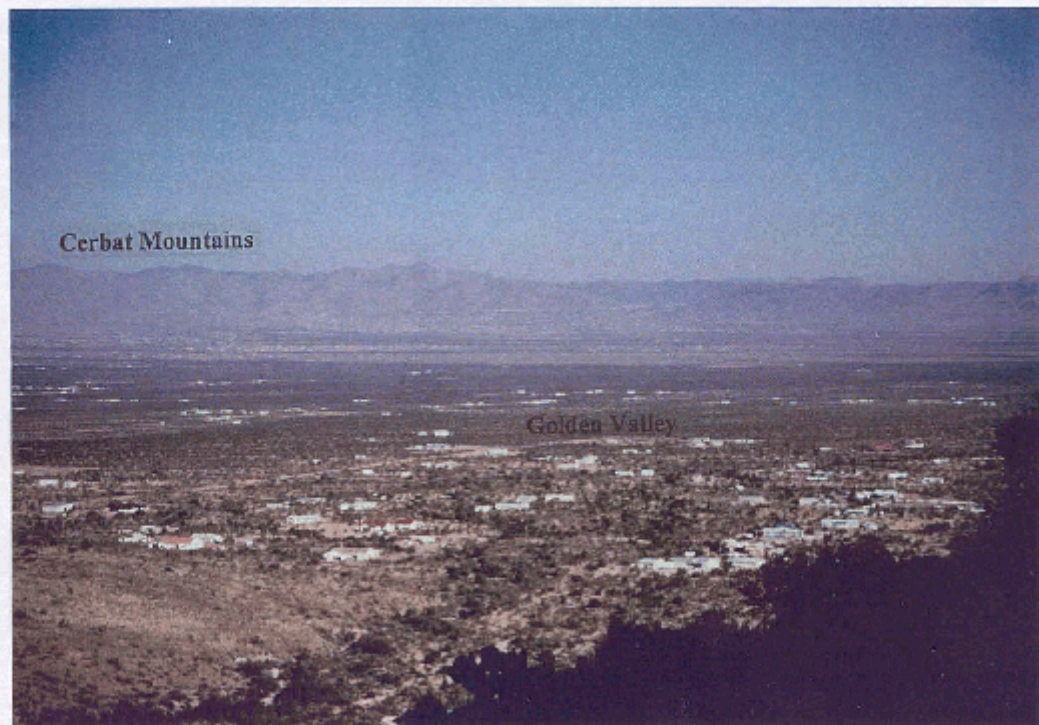
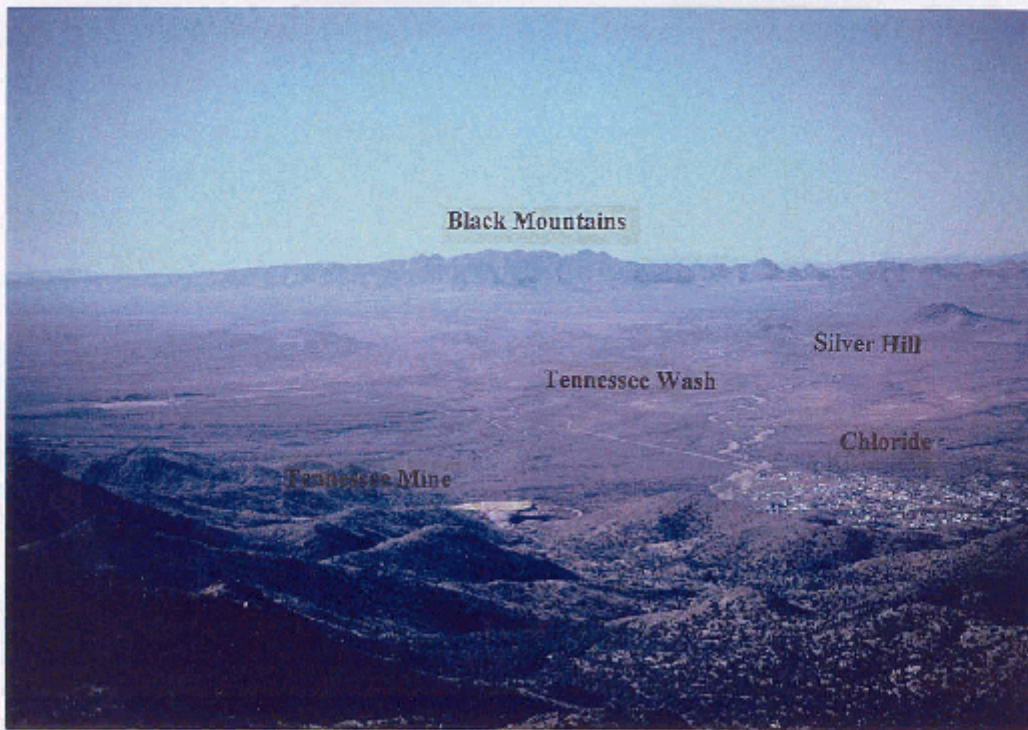
Cultural Setting

Resource management within the SVGB, particularly in mountain areas, is largely the responsibility of the Bureau of Land Management (BLM). However, valley areas contain significant acreage of private and State Trust lands. The city of Kingman is the Mohave County seat. It is also the population center of the SVGB with 33,588 residents (18,061 within the city limits) reported in 1997, which represents a 35 percent increase from 1990 (2). Situated in a low saddle between the Cerbat and Hualapai Mountains, Kingman is located in both the Sacramento Valley and Hualapai Valley groundwater basins. The city is supplied by a municipal water system which receives water from well fields located in both groundwater basins. One-third of Kingman residents are connected to the city's sewers while the remaining population utilizes septic systems for wastewater disposal (23). Bisected by Interstate 40, U.S. Highway 93, and a mainline of the Santa Fe-Burlington Northern railroad, Kingman serves as a modest service, trade, and transportation center as well as a bedroom community for the rapidly growing resort town of Laughlin, Nevada. Industry is a growing segment of the regional economy as evidenced by the construction of the North Star steel mill west of Kingman in the early 1990s.

Golden Valley is an unincorporated residential area located west of Kingman along Highway 68 (**Figure 2**). This low density community has experienced rapid growth within the past five years, and the current Golden Valley population is estimated at 7,000 (24). Residents within this area of the basin depend upon septic systems for wastewater disposal while domestic water needs are generally met by hauling water. However, some residents of Golden Valley are supplied by potable water from domestic wells or small public water systems (24).

The community of Chloride is located a few miles east of Highway 93 in the northern portion of the basin (**Figure 2**). Chloride was a booming mining town of almost 2,000 residents around the turn of the century; by 1995 the population had declined to approximately 420 people (33). The town was based on mining activity that occurred intermittently between the 1860s and the 1940s. However, most of the mines were closed during World War II because their ore production was not considered essential to the war effort. During this period of inactivity, many mine shafts became naturally flooded. The flooding, along with depleted ore reserves, hindered the reopening of most mines although a few operated until the 1970s (33). Few, if any, mines are currently operational (24). Gold and silver were

Figure 2. Views of the Communities of Chloride and Golden Valley



originally extracted; lead, zinc, and copper became increasingly important with improved milling methods and transportation facilities (33). Larger operations, such as the Tennessee Mine, processed ore on site. Remnants of mining and milling activity including tailings, waste-rock dumps, shafts, and adits are common in the area. Chloride municipal water is supplied by a well north of town in the Big Wash area in the Detrital Valley groundwater basin. Only a few small-capacity wells in town are still used, mainly for garden irrigation (33). Domestic wastewater in Chloride is treated by septic systems since there is no municipal sewer system (33). Many septic systems in the community are older and may pre-date codes regulating their installation. Other communities within the SVGB include Yucca, Topock, and Mineral Park. Yucca, located along Interstate 40 to the south of Kingman, is noteworthy because of its large automotive proving ground facility. Near the Colorado River is the resort community of Topock. Mineral Park (**Figure 3**), located to the east of Highway 93 between Chloride and Kingman, is where large-scale copper mining occurred after World War II. The Mineral Park Mine (currently operated by the Cyprus-Bagdad/Equitorial group) and the Emerald Isle Mine are the largest mining operations within the basin. The remainder of the basin consists of large ranches where low-density livestock grazing takes place on a combination of private and leased lands. In prime real estate locations, some ranches have been subdivided into residential lots for development. Widely dispersed residential homes are becoming a common feature of the SVGB landscape. There are no large-scale farming operations in the basin (24).

HYDROGEOLOGIC SETTING

Surface Water

There is no perennial surface water flow within the SVGB, although a few streams such as Rock Creek and Walnut Creek in the Hualapai Mountains flow almost continuously in their upper reaches (15). Generally, stream flow in the upper reaches of the mountain ranges is intermittent - flowing for several months in the spring - whereas surface water flow in the valley and its upland margins is ephemeral. The amount of precipitation on the valley floors is small and the loss of water to infiltration and evaporation is large (33). The stream beds in the mountains are primarily composed of coarse sand and gravel; bedrock occurs at shallow depths and frequently crops out (15). In contrast, valley stream beds are wide and shallow, composed mainly of sand (15). The main surface water drainage in the basin is Sacramento Wash (**Figure 3**), which originates north of Golden Valley, flows south, then west, and eventually discharges into the Colorado River at Topock. Surface runoff reaches Sacramento Wash only occasionally in direct response to long-duration winter storms or high-intensity summer thunderstorms; most runoff infiltrates the coarse alluvium at the base of the mountains, recharging the groundwater (15). The estimated mean annual flow of Sacramento Wash near Yucca is 400 acre-feet per year (af/yr)(15) while near Topock it is approximately 500 af/yr (6).

Groundwater

The most important aquifer in the SVGB consists of the alluvial deposits which underlie the valley floor and also occur within mountain canyons. Based on their lithologic and hydrologic properties, these alluvial deposits can be separated into older, intermediate, and younger alluvial, with the younger alluvium further subdivided into piedmont and stream deposits (15). The older alluvium aquifer yields and stores the greatest quantity of water in the basin (6). The mountains that form the basin boundaries consist predominantly of granitic, volcanic, and metamorphic rocks with some limited outcrops of

Figure 3. Views of Mineral Park Mine and Sacramento Wash.



sedimentary rocks. While all rock types have been tapped to produce water, volcanic rocks are the most important source of water in mountain areas (15). Characteristics of each rock type and alluvial deposit are provided below while their spatial extent is illustrated in **Figure 4**. For this study, the older, intermediate, and younger alluvium are considered as the *alluvial aquifer* which lies beneath the valley floor and is the basin's principal water-bearing unit. Granitic, metamorphic, sedimentary, and volcanic rock are considered the *hardrock aquifer* that has limited water-bearing potential and is located beneath the mountainous areas that form the perimeter of the basin (27).

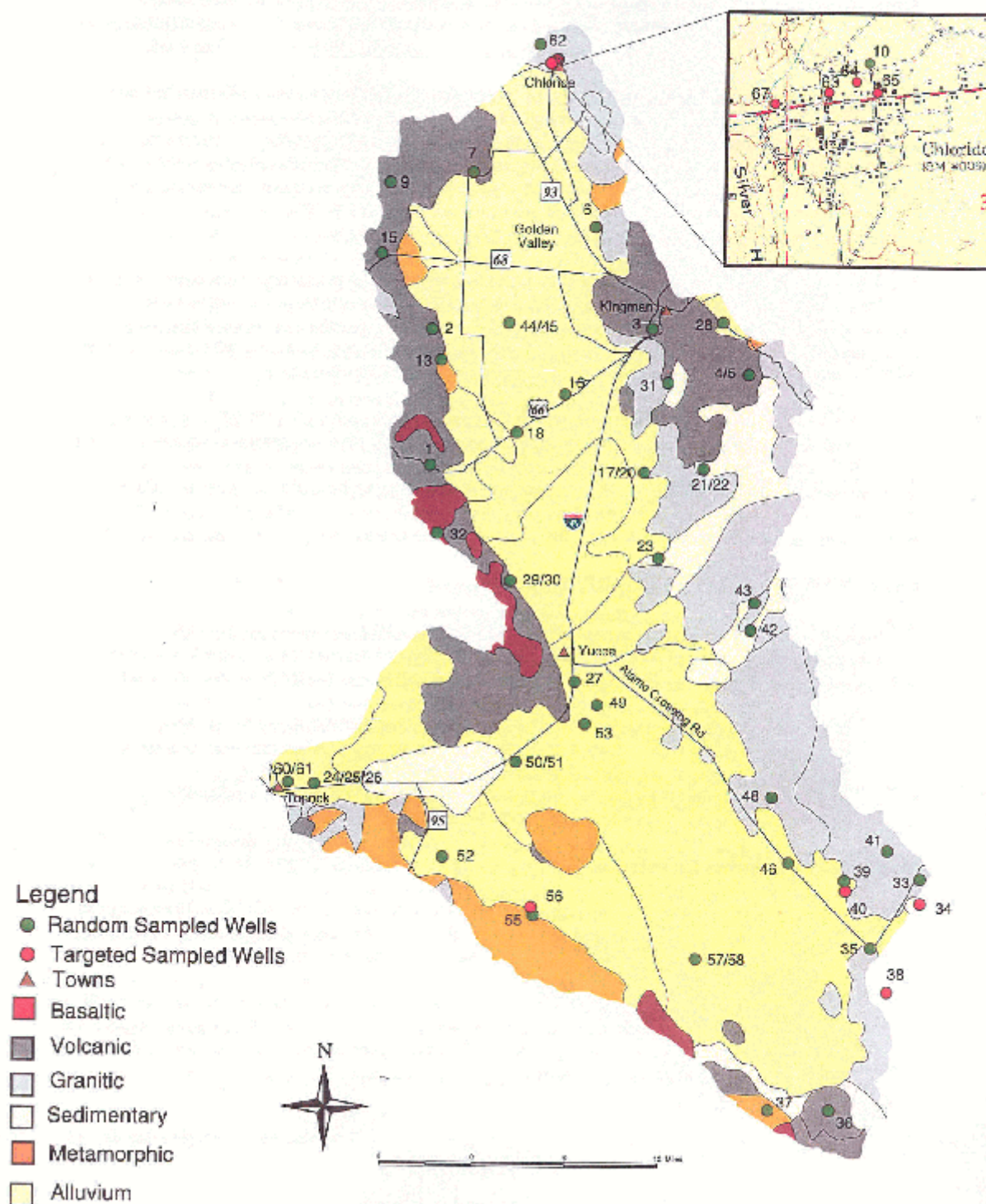
Older Alluvium - This unit is the lowermost sedimentary deposit in the valley and is only exposed in isolated outcrops near the mountains. The older alluvium is composed of moderately consolidated fragments of granite, schist, gneiss, and volcanic rocks in a silty clay and contains interbeds of weakly-consolidated tuff and agglomerate (15). Its composition transitions from pebble to boulder-sized fragments near the mountains to coarse sand and interbedded clay and silt in the valleys (15). The older alluvium is the principal water producing aquifer in the SVGB and can yield moderate to large quantities of water. This aquifer is estimated to extend over an area of 500 square miles and stores approximately 7 million acre-feet (af) to a depth of 1,200 feet, with a saturated thicknesses of 0 - 600 feet (6).

Intermediate Alluvium - This unit is the middle sedimentary deposit in the valley, ranging from 200 - 500 feet thick. The intermediate alluvium is an extensive, near-surface deposit underlying much of the valley floor but is exposed in discontinuous outcrops near the mountains and within mountain canyons (15). It is composed of weakly to moderately consolidated fragments of granite, schist, gneiss, and volcanic rocks. Similar to the older alluvium, grain size decreases from pebble to boulder-sized grains near the mountains to fine gravel, sand, and silt in the central valley (15). The intermediate alluvium is capable of transmitting and storing large quantities of groundwater but is less important since most of the unit lies above the water table. Where this unit overlies bedrock at shallow depths near the mountainous perimeter of the basin, however, wells can yield up to 50 gallons per minute (gpm) (15).

Younger Alluvium - This unit is divided into piedmont and stream deposits based on lithologic properties and degree of cementation (15). Piedmont deposits up to 50 feet in thick overlie the intermediate and older alluvium on terraces, alluvial fans, piedmont slopes, and valley floors. These consist of poorly consolidated silt to gravel-size fragments of granite, schist, gneiss, and volcanic rocks. Piedmont deposits are above the water table, however, and do not supply any water. Stream deposits are typically not more than a few feet thick and occur exclusively in stream channels within the basin. The unconsolidated sand and gravel-size fragments of granite, schist, gneiss, and volcanic rocks yield small amounts of water to wells in mountain canyons where the unit is underlain by impermeable bedrock (15).

Granitic, Metamorphic, and Volcanic Rocks - Granitic and metamorphic rocks constitute major portions of the Cerbat, Hualapai, and Mohave Mountains and form the basement complex in the valley which limits downward movement of groundwater (15). The granitic and metamorphic rocks generally do not yield water except along fractures and in weathered zones. Yields average from 1 to 5 gpm (15). Volcanic rocks constitute major portions of the Black and McCracken Mountains and form the topographic saddle where Kingman is located between the Cerbat and Hualapai Mountains. The volcanic rocks are divided into older and younger deposits. The older volcanic rock unit, which consists of andesite and latite flows and tuff beds, transmits some water through fracture zones and interbeds of tuff. However, the unit is generally too fine grained or cemented to readily yield water (15). The younger

Figure 4 - Sacramento Valley Groundwater Basin
Rock Types and Sampling Sites



volcanic rocks consist of basalt flows, basaltic andesite flows and tuff, and rhyolite tuff. It constitutes an important aquifer near Kingman where two large fault zones provide passage for the storage and movement of water (15). City wells in the younger volcanic rock produce, on average, 450 af/yr (27).

Groundwater Recharge, Levels, and Use - Recharge to the alluvial deposits is mostly from infiltration of streamflow near the apexes of the dissected alluvial fans that extend into the mountain canyons. Water moves downslope through the fan deposits to the major aquifer in the valley, the older alluvium. This mountain front recharge is estimated at 4,000 af/yr (6). Recharge from precipitation falling on the valley floor is considered negligible because of the high evapotranspiration rate and the presence of relatively impervious layers of clay and caliche near the land surface (15). The basin was considered to be in a steady-state hydrologic condition as of 1990 (6). Depth to water varies widely, from greater than 1,000 feet below land surface (bls) in the northern end of the basin to less than 100 feet bls near the Colorado River (27). Groundwater movement is from the mountains to the valleys and downgradient to the Colorado River. It parallels the flow of Sacramento Wash, heading southward until turning westward near the town of Yucca. Groundwater discharge from the basin into the Colorado River near Topock is estimated to be 1,000 af/yr (6).

From 1991 to 1995, municipal withdrawals within the basin range from 6,000-7,100 af/yr. Industrial withdrawals during the same period have fluctuated between 94-140 af/yr (6). Irrigated agriculture is an insignificant water usage in this basin. Historically, mines in the northern portion of the basin withdrew large amounts of groundwater. Groundwater pumpage was at a record high of 8,000 af/yr in 1978 during the peak of the mining activity at Mineral Park (27); however, this mine is now largely inactive. Springs within the basin issue from hardrock areas, but none are known to emerge from the valley alluvium (15).

GROUNDWATER SAMPLING RESULTS

To characterize the regional groundwater quality of the SVGB, ADEQ personnel sampled 48 groundwater sites consisting of 41 wells and 7 springs. Of these 48 sites, 40 were random sites and 8 were targeted sites (**Figure 4**). The numbers and types of samples collected for this study are:

- < At 48 sites, samples were collected for Safe Drinking Water (SDW) inorganic analyses.
- < At 48 sites, samples were collected for SDW Volatile Organic Compounds (VOCs) analyses.
- < At 48 sites, samples were collected for perchlorate analyses.
- < At 47 sites, samples were collected for hydrogen, oxygen, and nitrogen isotope analyses.
- < At 40 sites, samples were collected for SDW radiochemistry analyses.

Water Quality Standard Exceedances

ADEQ is the designated state lead for all purposes of the Clean Water Act (§49-202A) and is required to collect water quality samples and compare their analytical results with water quality standards (3). Thus, ADEQ evaluates the suitability of water for domestic uses based upon the following criteria:

- < Federal Safe Drinking Water (SDW) Primary Maximum Contaminant Levels (MCLs) are health-based water quality standards that set the maximum concentration levels of a given constituent for water supplied by a public-water system (PWS) (42). Primary MCLs are based on a lifetime daily consumption of two liters of water.

- < State of Arizona aquifer water quality standards apply to aquifers that are classified for drinking water use (3). Currently, all aquifers within Arizona are classified for drinking water use. These State standards are almost identical to the federal Primary MCLs.
- < Federal SDW Secondary MCLs are unenforceable aesthetic-based water quality guidelines that define the maximum concentration of a constituent that can be present without unpleasant taste, color, odor, or other aesthetic effect on drinking water (42). Water with Secondary MCL exceedances may be unpleasant to drink and may cause cosmetic effects such as skin or teeth discoloration, but it is not considered to be a health concern.

Health-based Primary MCLs and State of Arizona aquifer water quality standards were exceeded at 22 of 48 sites (**Figure 5**). Constituents which exceeded Primary MCLs (**Table 1**) include gross alpha (18 sites)(**Figure 6**), nitrate (6 sites)(**Figure 6**), fluoride (4 sites), radium-226 plus radium-228 (4 sites), and antimony (2 sites). In addition, the proposed Primary MCL for uranium was exceeded at 17 sites. Potential health effects of Primary MCL exceedances include cancer (gross alpha, antimony, radium-226 plus radium-228), and methemoglobinemia or blue baby syndrome (nitrate), skeletal damage (fluoride). Perchlorate poses health risks because it can affect the thyroid gland, which controls metabolism, growth, and development (47). Aesthetics-based Secondary MCL water quality standards were exceeded at 28 of 48 sites (**Figure 5**). Constituents and sites which exceeded Secondary MCLs (**Table 2**) include TDS (24)(**Figure 7**), fluoride (16) (**Figure 7**), chloride (7), sulfate (7), manganese (3), and iron (2).

Analytical Results

SDW Inorganic and Radiochemical Constituents - Results for inorganic and radiochemical constituents for 48 groundwater sample sites are reported in **Appendix A** as well as summarized in **Table 3**. This table consists of various statistical indices including upper and lower 95 percent confidence intervals ($CI_{0.95}$) which indicate that a certain percentage of a constituent's population lies within a stated confidence interval. For instance, if 100 additional sites were sampled in the SVGB, the constituent levels for 95 of those sites would be expected to fall within the 95 percent confidence interval. This index is a useful tool for comparing targeted groundwater sites by identifying constituent concentration outliers that may be produced by groundwater quality impacts from specific land uses. Confidence intervals determined by aquifer and geology are reported in **Appendix B** and **Appendix C**. Information on locations and characteristics of groundwater sample sites is provided in **Appendix D**.

SDW Volatile Organic Compounds (VOCs) - Analytical results of the VOC samples revealed no detections of any of the 60 SDW compounds (**Appendix A**), including the gasoline oxygenate, Methyl Tertiary Butyl Ether (MTBE). See **Appendix E** for the analytes on the EPA 502.2 VOC list.

Perchlorate - Perchlorate originates as a contaminant in the environment from the solid salts of ammonium, potassium, sodium, and lithium perchlorate. The perchlorate part of the salts is highly soluble in water and the resultant anion (ClO_4^-) is exceedingly mobile in aqueous systems. Because of its high chemical stability, it can persist for many decades under typical groundwater conditions (47). This man-made inorganic salt, used in the manufacture of solid fuel propellants and explosives, was detected at four sites in the northwest portion of the basin at levels ranging from just above the 0.004 micrograms per liter (Fg/l) MRL to 0.021 Fg/l (**Appendix A**). Although no current federal water quality standard exists for

Figure 5 - Water Quality Exceedances and QA/QC Sites in the SVGB

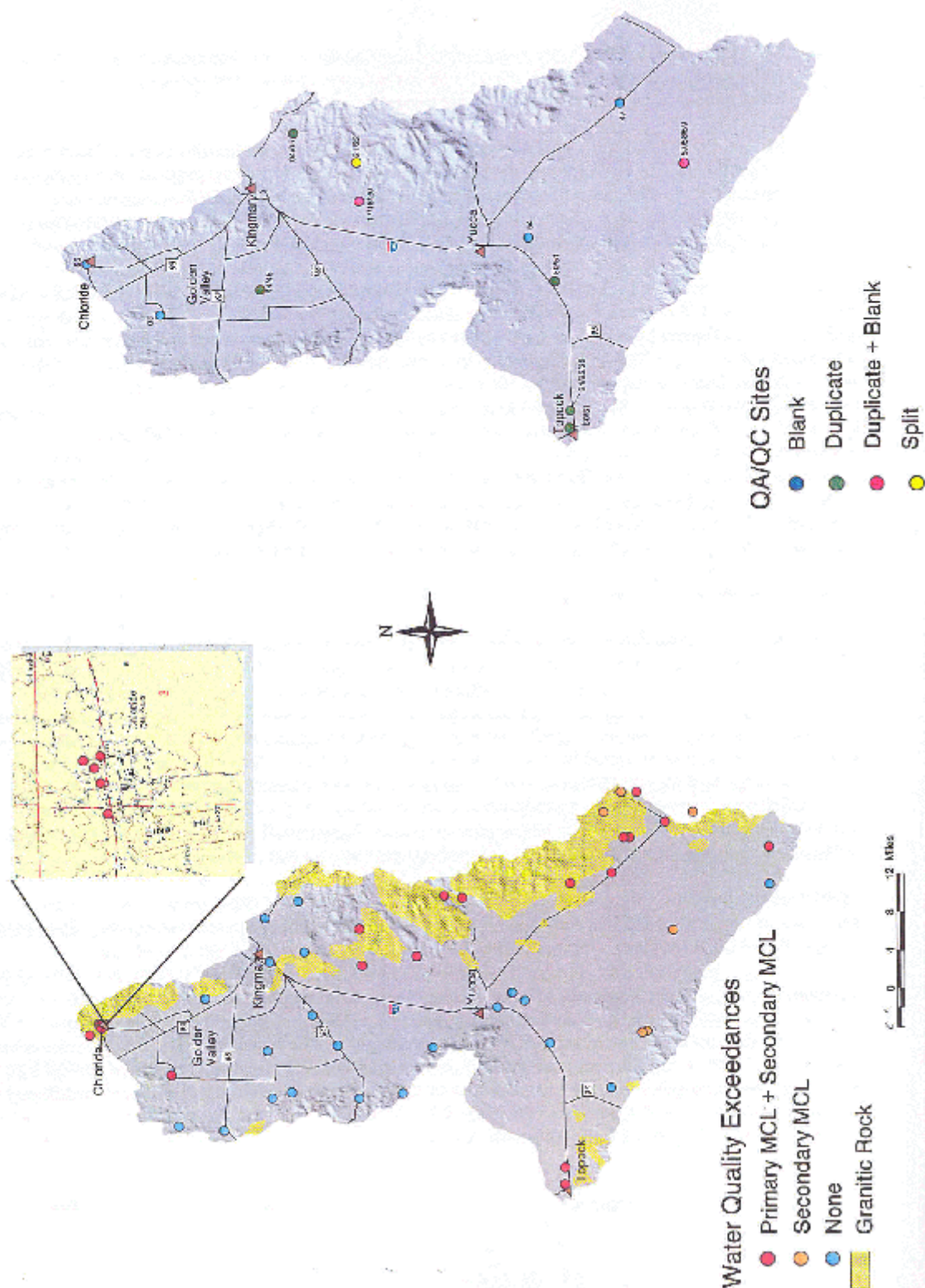


Table 1. SVGB Sites Exceeding Health-Based Water Quality Standards

Constituent	Primary MCL	Levels of Sites Exceeding Primary MCLs			
Nutrient Constituents					
Nitrite (NO ₂ -N)	1.0	--			
Nitrate (NO ₃ -N)	10.0	SV-06 = 18 SV-63 = 18	SV-07 = 28 SV-64 = 15	SV-17/20 = 11 SV-65 = 19	
Trace Constituents					
Antimony (Sb)	0.006	SV-63 = 0.0067	SV-65 = 0.0068		
Arsenic (As)	0.05	--			
Barium (Ba)	2.0	--			
Beryllium (Be)	0.004	--			
Cadmium (Cd)	0.005	--			
Chromium (Cr)	0.1	--			
Fluoride (F)	4.0	SV-24/25 = 4.5	SV-35 = 5.7	SV-42 = 4.0	SV-60/61 = 5.9
Mercury (Hg)	0.002	--			
Nickel (Ni)	0.1				
Selenium (Se)	0.05	--			
Thallium (Tl)	0.002	—			
Radiochemistry Constituents					
Gross Alpha	15	SV-10 = 73 SV-34 = 30 SV-40 = 50 SV-48 = 93 SV-65 = 190	SV-17/20 = 18 SV-35 = 33 SV-42 = 96 SV-62 = 200 SV-67 = 160	SV-21 = 40 SV-36 = 33 SV-43 = 53 SV-63 = 1100	SV-23 = 22 SV-39 = 15 SV-46 = 53 SV-64 = 140
Ra-226 + Ra-228	5	SV-10 = 7.8	SV-46 = 20	SV-63 = 23	SV-65 = 15
Uranium	20 (proposed)	SV-10 = 56 SV-34 = 67 SV-40 = 45 SV-46 = 160 SV-64 = 330	SV-17/20 = 27 SV-35 = 67 SV-41 = 22 SV-48 = 120 SV-65 = 190	SV-21 = 77 SV-36 = 48 SV-42 = 220 SV-62 = 230 SV-67 = 240	SV-23 = 25 SV-39 = 45 SV-43 = 28 SV-63 =1500

All units are milligrams per liter (mg/l) except picocuries per liter (pCi/l) for gross alpha & Ra-226+Ra-228, and micrograms per liter (ug/l) for uranium.

Figure 6 - Gross Alpha and Nitrate Levels in Groundwater in the SVGB

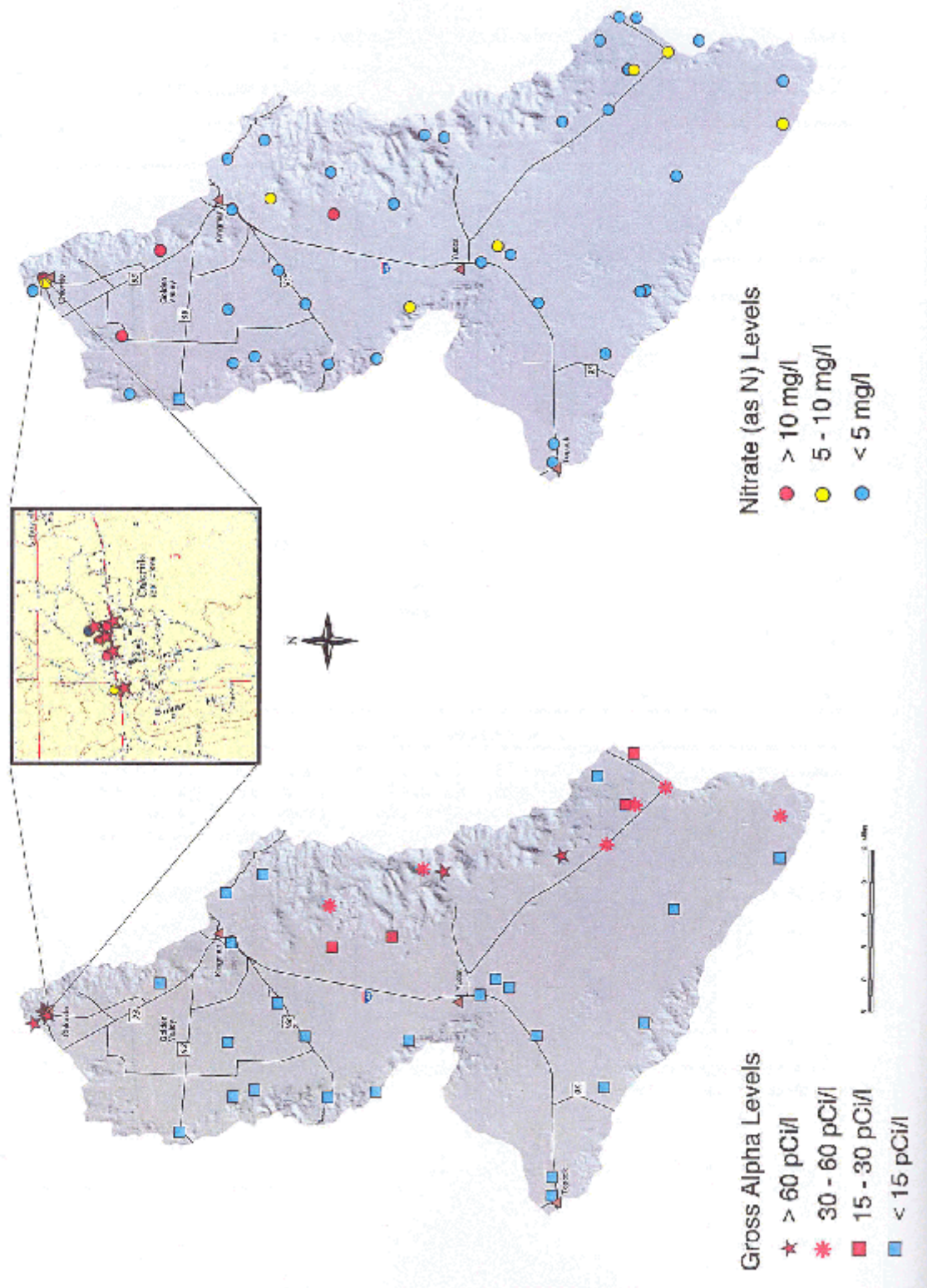


Table 2. SVGB Sites Exceeding Aesthetics-Based Water Quality Standards

Constituent	Secondary MCL	Sites Exceeding Secondary MCLs			
Physical Parameters					
pH - field	6.5 to 8.5	--			
General Mineral Constituents					
TDS	500	SV-06 = 890	SV-07 = 630	SV-10 = 750	SV-17/20 = 595
		SV-21/22 = 847	SV-24/25 = 670	SV-33 = 720	SV-34 = 1900
		SV-35 = 630	SV-36 = 550	SV-38 = 830	SV-39 = 1800
		SV-40 = 3700	SV-41 = 1400	SV-42 = 830	SV-43 = 630
		SV-46 = 540	SV-56 = 1800	SV-60/61 = 1100	SV-62 = 750
		SV-63 = 2200	SV-64 = 1400	SV-65 = 1900	SV-66 = 1000
Major Ions					
Chloride (Cl)	250	SV-34 = 390	SV-39 = 420	SV-40 = 940	SV-60/61 = 435
		SV-63 = 490	SV-64 = 360	SV-65 = 350	
Sulfate (SO ₄)	250	SV-34 = 570	SV-39 = 480	SV-40 = 1300	SV-41 = 600
		SV-56 = 920	SV-63 = 660	SV-65 = 600	
Trace Constituents					
Fluoride (F)	2.0	SV-17/20 = 2.9	SV-21/22 = 2.3	SV-23 = 2.3	SV-24/25 = 4.5
		SV-33 = 3.2	SV-35 = 5.7	SV-38 = 2.1	SV-39 = 2.3
		SV-40 = 2.3	SV-41 = 2.8	SV-42 = 4.0	SV-43 = 3.0
		SV-46 = 3.6	SV-48 = 3.1	SV-57/58 = 2.5	SV- 60/61 = 5.9
Iron (Fe)	0.3	SV-33 = 0.42	SV-41 =1.60		
Manganese (Mn)	0.05	SV-41 = 0.064	SV-55 = 0.18	SV-63 = 0.21	
Silver (Ag)	0.1			--	
Zinc (Zn)	5.0			--	

All units are milligrams per liter (mg/l) except for pH which is in standard units (su).

Figure 7 - Fluoride and TDS Levels in Groundwater of the SVGB

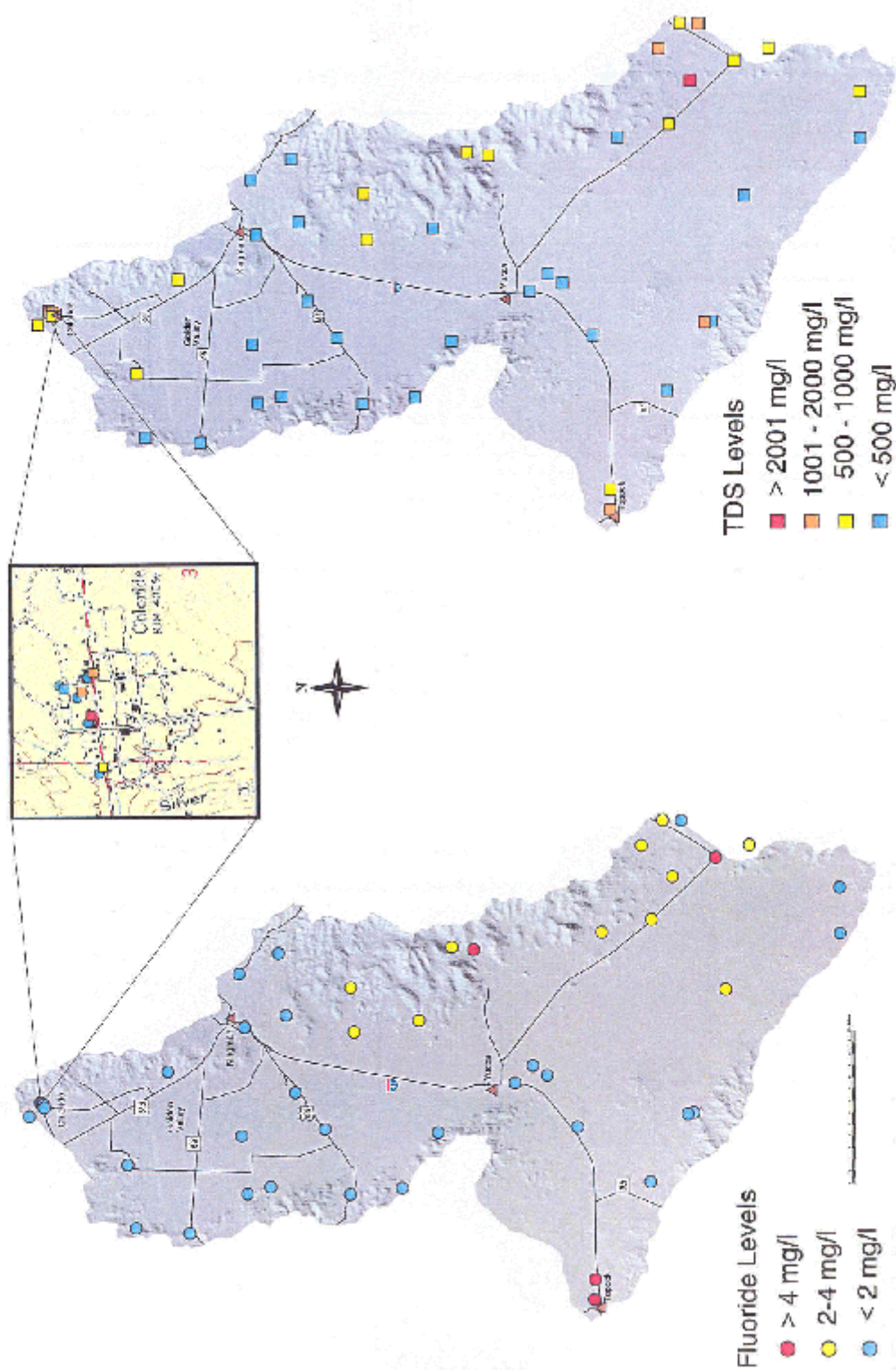


Table 3. Summary Statistics for SVGB Groundwater Quality Data

Constituent	Minimum Reporting Limit (MRL)	Number of Sites Over MRL	Lower 95% Confidence Interval	Mean	Upper 95% Confidence Interval
Physical Parameters					
Temperature (°C)	N/A	N/A	21.7	23.4	25.1
pH-field (su)	N/A	N/A	7.35	7.46	7.57
Turbidity (ntu)	0.01	48	0.71	2.38	4.06
General Mineral Constituents					
Total Alkalinity	2.0	48	195	220	246
Phenol. Alkalinity	2.0	0	>90% of data below MRL		
SC-field (FS/cm)	N/A	N/A	893	1138	1384
SC-lab (FS/cm)	N/A	N/A	827	1092	1356
Hardness	10.0	48	278	383	488
TDS	10.0	48	555	750	945
Major Ions					
Calcium	5.0	48	72	97	122
Magnesium	1.0	48	23	35	47
Sodium	5.0	48	81	108	135
Potassium	0.5	48	3.9	6.2	8.5
Bicarbonate	2.0	48	242	273	304
Chloride	1.0	48	81	131	181
Sulfate	10.0	48	96	172	248
Nutrient Constituents					
Nitrate (as N)	0.02	44	2.74	4.47	6.20
Nitrite (as N)	0.02	1	>90% of data below MRL		
Ammonia	0.02	4	>90% of data below MRL		
TKN	0.05	27	0.03	0.18	0.32
Total Phosphorus	0.02	9	0.01	0.19	0.28

All units are milligrams per liter (mg/l) except where noted with physical parameters.

Table 3. Summary Statistics for SVGB Groundwater Quality Data--Continued

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Mean	Upper 95% Confidence Interval
Trace Constituents					
Antimony	0.005	4	>90% of data below MRL		
Arsenic	0.01	6	0.010	0.014	0.018
Barium	0.1	0	>90% of data below MRL		
Beryllium	0.0005	1	>90% of data below MRL		
Boron	0.1	40	0.204	0.263	0.322
Cadmium	0.001	0	>90% of data below MRL		
Chromium	0.01	7	0.001	0.042	0.083
Copper	0.01	6	0.014	0.021	0.029
Fluoride	0.20	47	1.28	1.68	2.08
Iron	0.1	4	>90% of data below MRL		
Lead	0.005	1	>90% of data below MRL		
Manganese	0.05	3	>90% of data below MRL		
Mercury	0.0005	0	>90% of data below MRL		
Nickel	0.1	0	>90% of data below MRL		
Selenium	0.005	13	0.007	0.009	0.010
Silver	0.001	0	>90% of data below MRL		
Thallium	0.005	0	>90% of data below MRL		
Zinc	0.05	22	0.007	0.009	0.010
Radionuclide Constituents					
Gross alpha (pCi/l)	Varies	39	6.1	62.5	119.0
Gross beta (pCi/l)	Varies	39	6.0	36.7	67.3
Radium 226 + 228 (pCi/l)	Varies	4	>90% of data below MRL		
Uranium	Varies	19	24.3	184.1	344.0

All units are mg/l except where noted with radionuclides.

perchlorate, Arizona has set a provisional Drinking Water Health-Based Guidance Level at 31 Fg/l while California has established an interim health standard of 18 Fg/l (4). No sites exceeded Arizona standards; one site exceeded California standards.

Isotopes of Hydrogen (Deuterium), Oxygen, and Nitrogen - Analyses of stable isotopes of oxygen (oxygen-18 or ^{18}O) and hydrogen (deuterium or D) are used in this study to describe the origin of groundwater in the basin. Since stable oxygen and hydrogen are intimately associated in the water molecule, these isotopes are usually covariant and are typically discussed together. Since the source of groundwater is typically precipitation, its spatial and temporal isotopic content variations can be used to investigate groundwater recharge. Stable isotopes of nitrogen are used in this study in an attempt to determine a source for nitrates found in the groundwater. These three isotope samples were collected at 47 sites in the SVGB. Analytical results (**Appendix A**) are reported in parts per thousand per mil ($‰$) relative to Standard Mean Ocean Water which is the standard reference water. The upper 95% confidence value, mean and lower 95% confidence value were -69.2, -70.8, and -72.4 $‰$ for deuterium, -9.4, -9.7, and -9.9 $‰$ for oxygen-18, and 6.8, 8.9, and 11.1 $‰$ for nitrogen-15.

GROUNDWATER DATA ANALYSIS

Groundwater Composition

A major objective for this study was to characterize SVGB groundwater using qualitative classifications, water chemistry types, correlation of various constituent concentrations, and flowpath evolution.

General Summary - The SVGB can be described as having predominately *fresh, neutral-to-slightly alkaline, very hard* groundwater. TDS concentrations were below 1,000 mg/l at 38 sites, 9 sites had *slightly saline* water (TDS levels between 1,000 - 3,000 mg/l) and 1 site had *moderately saline* water (TDS levels between 3,000 - 10,000 mg/l)(18). Levels of pH were generally *neutral-to-slightly alkaline* as 42 sites had pH levels of 7 standard units (su) or above. Only 6 sites had *slightly acidic* groundwater below a pH of 7 su (18). Hardness levels from 21 sites ranged from *very hard* water (> 300 mg/l), to 13 sites having *hard* water (150 - 299 mg/l), 13 sites having *moderately hard* water (75 - 149 mg/l), and 1 site having *soft water* (< 75 mg/l) (13). Most trace constituents were rarely detected, including aluminum, antimony, barium, beryllium, boron, cadmium, chromium, iron, lead, manganese, mercury, selenium, silver, and thallium. Only arsenic, barium, copper, fluoride, and zinc were detected at more than 10 percent of the sites at levels above the Arizona Department of Health Services (ADHS) Minimum Reporting Levels (MRLs). Nutrient constituent concentrations were also typically low with only nitrate and total Kjeldahl nitrogen (TKN) detected at more than half the sites above ADHS MRLs. Nitrate (as nitrogen) concentrations ranged from natural background (10 sites at < 0.2 mg/l), to those that may or may not indicate human influence (18 sites at 0.2 - 3.0 mg/l), to those that may result from human activities (14 sites at 3.0 - 10.0 mg/l), and those that probably result from human activities (6 sites at > 10.0 mg/l) (23).

Groundwater Chemistry - The chemical composition of samples collected from 48 sites in the SVGB is illustrated using Piper trilinear diagrams. The Piper trilinear diagrams illustrate the following patterns:

- < The cation triangle diagram (lower left in **Figure 8**) illustrates that calcium is the dominant (> 50 percent) cation at 9 sites whereas sodium is the dominant cation at 7 sites, and the remaining 32 sites have no dominant cation.

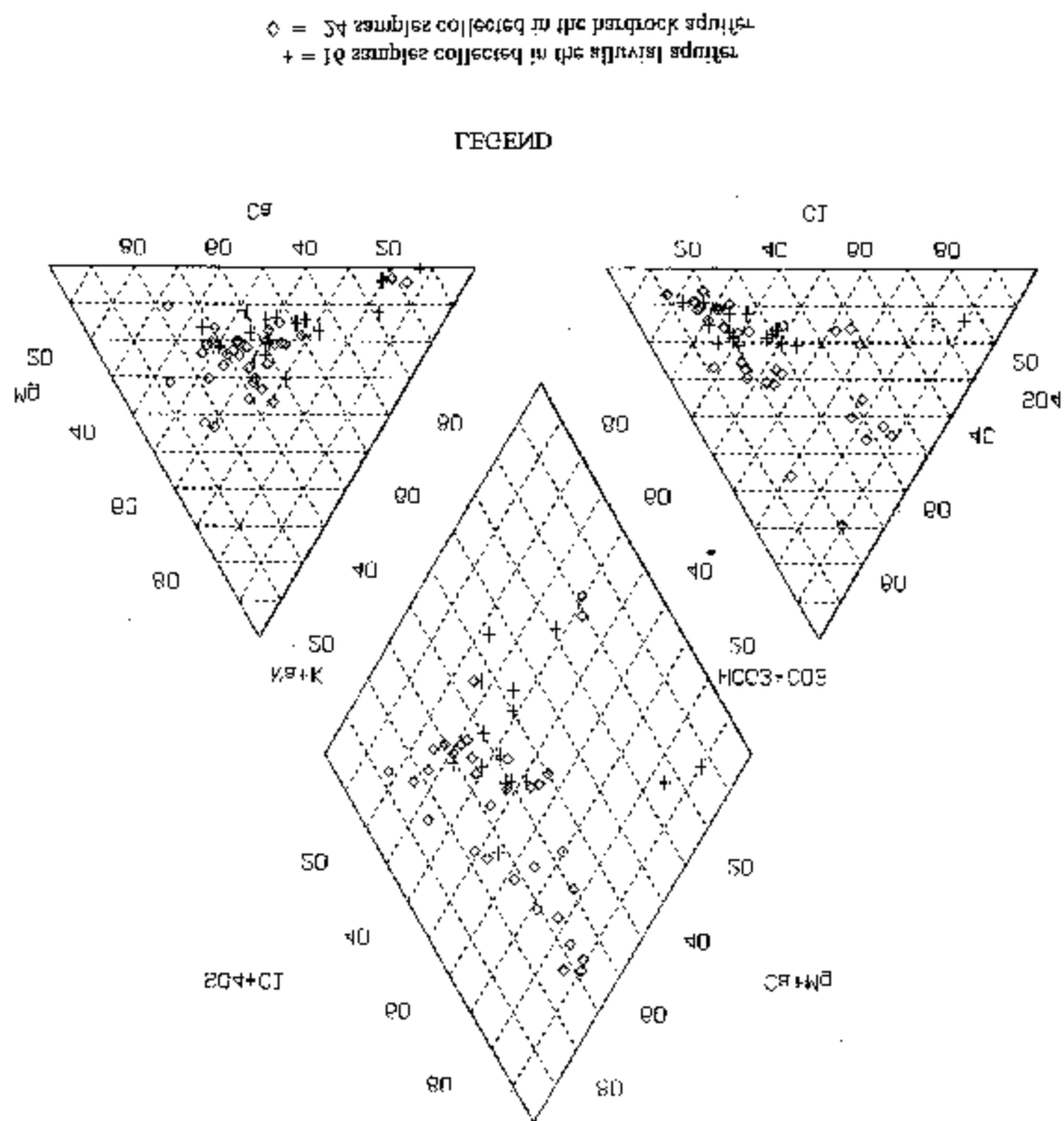


Figure 8. Chemistry of Groundwater Sites

- < The anion triangle diagram (lower right in **Figure 8**) illustrates that bicarbonate is the dominant (> 50 percent) anion at 30 sites, chloride and sulfate are the dominant anions at 2 sites apiece, and the remaining 14 sites have no dominant anion.
- < The cation-anion diamond diagram (center in **Figure 8**) illustrates that 24 sites have a calcium-bicarbonate chemistry, 16 sites have a calcium-sulfate chemistry, 6 sites have a sodium-bicarbonate chemistry, and 2 sites have a sodium-sulfate chemistry.

Grouping the 48 groundwater sites by aquifer illustrates that 14 of 16 calcium-sulfate sites are from the hardrock aquifer, while the 2 sodium-sulfate sites are from the alluvial aquifer.

Parameter Level Covariation - To further characterize the groundwater composition, constituent concentrations from random samples were compared to other constituent concentrations using Pearson's Correlation Coefficient test in order to scrutinize the strength of the association. The results of each combination of constituents were examined for statistically-significant, positive or negative correlations. A positive correlation occurs when, as a constituent concentration increases or decreases, the concentration of another constituent also correspondingly increases or decreases. A negative correlation occurs when, as a constituent concentration increases, the concentration of another constituent decreases.

At the 40 random sites, significant ($p \leq 0.05$) relationships included TDS and specific conductivity (SC) positively correlated with calcium, magnesium, sodium, bicarbonate, chloride, sulfate, hardness, fluoride, and boron; in contrast, a negative correlation occurred with pH-field. Two constituents which sometimes exceeded health-based water quality standards exhibited unique patterns. Nitrate had negative correlations with bicarbonate, hardness, sulfate, and turbidity. In contrast, gross alpha and gross beta had positive correlations with bicarbonate. Depending on the dominant cation, two patterns were present:

- < Positive correlations occurred among calcium (**Figure 9**), magnesium, bicarbonate, sulfate, and hardness while negative correlations with pH-field and temperature; and
- < Positive correlations occurred among sodium (**Figure 10**), chloride, sulfate, fluoride, and boron.

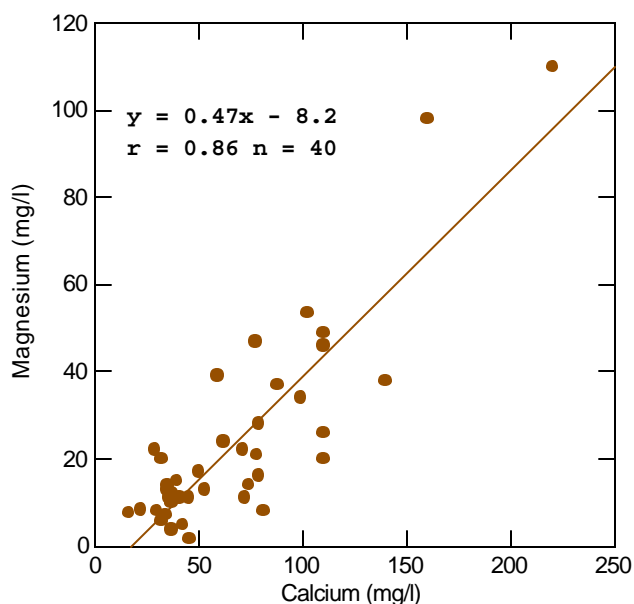
Constituent concentrations from the 16 alluvial aquifer random sites were compared with one another to identify significant ($p \leq 0.05$) correlations. Unique patterns occurred with gross alpha, which was positively correlated with temperature and negatively correlated with bicarbonate. Other patterns were:

- < Positive correlations occurred among sodium, TDS, SC, chloride, sulfate, boron, and fluoride.
- < Positive correlations occurred among calcium, magnesium, bicarbonate, hardness, nitrate, turbidity, and gross alpha and a negative correlation occurred with pH-field.

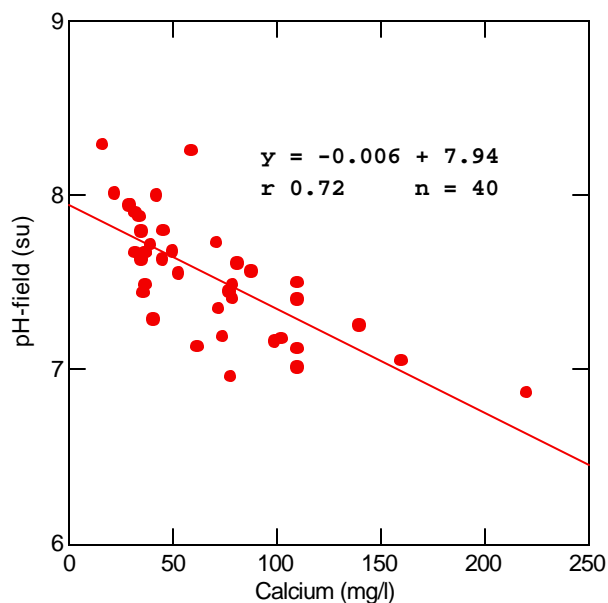
Constituent concentrations from the 24 hardrock aquifer random sites were compared with one another to identify significant ($p \leq 0.05$) correlations. Fluoride had a unique pattern, as it was negatively correlated with temperature. Two general patterns were revealed by the results of this statistical testing:

- < Positive correlations occurred between sodium and the following parameters: TDS, SC, bicarbonate, chloride, sulfate, boron, and fluoride.

Figure 9. Magnesium and pH as a Linear Function of Calcium.

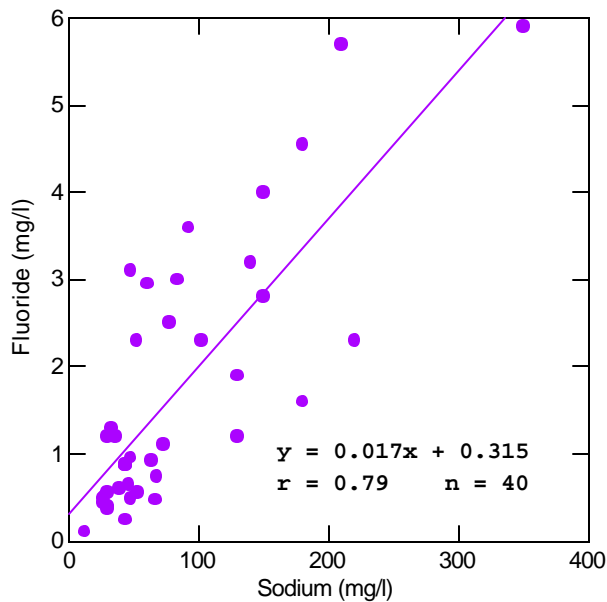


The graph to the left illustrates a positive correlation between calcium and magnesium. This relationship was shown to be significant ($p \leq 0.01$) by the Pearson correlation statistical test as well as regression analysis. Although these cations are the principal cause of hardness, their geochemical behavior can be substantially different (19). A similar correlation between concentrations of calcium and magnesium were also found in the Douglas (38), Virgin River (39), and Yuma (40) groundwater basins in Arizona. In the SVGB, bicarbonate, sulfate, hardness, and total alkalinity also had positive correlations with calcium and magnesium.

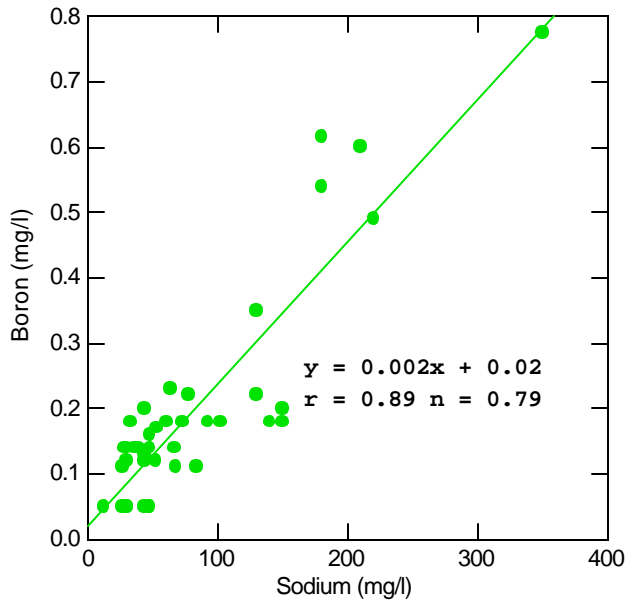


The graph to the left illustrates a negative correlation between calcium and pH-field. This relationship was shown to be significant ($p \leq 0.01$) by the Pearson Correlation Coefficient statistical test as well as regression analysis. This pH-calcium pattern has been found in other groundwater studies and may be related to cation exchange which results in chemical reactions that lower calcium concentrations and raise pH values (19). Calcium is more soluble in acidic waters (46). Recharge areas typically contain high levels of calcium and neutral pH values (6.9 - 7.4 su). In downgradient areas, calcium concentrations often decline with pH values

Figure 10. Fluoride and Boron as a Linear Function of Sodium.



The graph to the left illustrates a positive correlation between sodium and fluoride. This relationship was shown to be significant ($p \leq 0.01$) by the Pearson Correlation Coefficient statistical test. Recharge areas frequently contain low concentrations of sodium and trace elements such as fluoride and boron. In contrast, downgradient areas frequently have sodium as the dominant cation along with increased concentrations of fluoride and boron (29). Natural softening by cation exchange produces alkaline-oxidizing conditions that may result in both elevated sodium levels as well as mobilizing trace elements found in the basin-fill sediments (19).



The graph to the left illustrates a positive correlation between sodium and boron. This relationship was shown to be significant ($p \leq 0.01$) by the Pearson Correlation Coefficient statistical test. Similar sodium-boron patterns were found in the Douglas (38), Virgin River (39), and Yuma (40) groundwater basins in Arizona. Robertson (29) reported that boron concentrations in Arizona tend to be lower in southeastern basins and higher in western basins; a finding recent ADEQ ambient groundwater studies support.

- < Positive correlations occurred among TDS, SC, hardness, calcium, magnesium, chloride and sulfate; a negative correlation occurred with pH-field.

Flowpath Evolution - In the alluvial aquifer, groundwater movement parallels the course of the Sacramento Wash (30). Constituent concentrations varied at sites along this groundwater flowpath and are characterized by two general patterns. Constituents such as calcium (**Figure 11**), magnesium, bicarbonate (**Figure 12**), and hardness tend to have concentrations that decrease downgradient. In contrast, constituents such as sodium (**Figure 11**), chloride (**Figure 12**), fluoride, and boron tend to have concentrations that initially decrease and then increase dramatically in downgradient areas.

Groundwater Quality Spatial Patterns

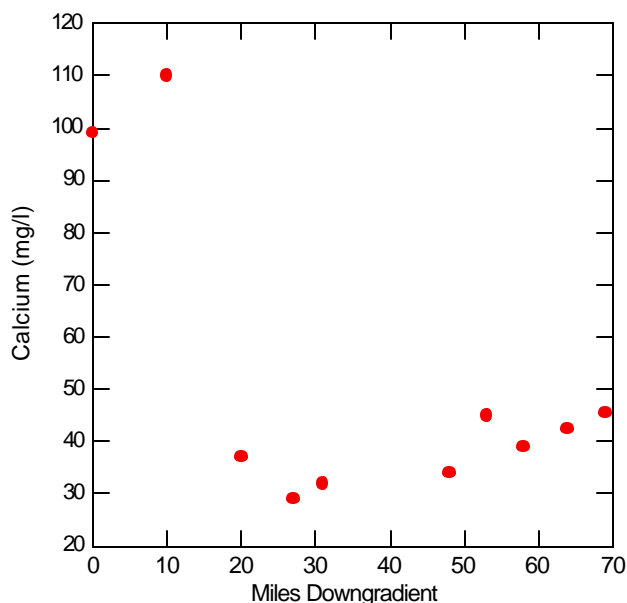
An objective of the SVGB study was to assess the spatial variation of groundwater quality constituent concentrations among aquifers, rock types, sub-basins, and with groundwater depth.

Aquifer Comparison - The alluvial and hardrock aquifers were compared by applying the Kruskal-Wallis test to analytical results collected from the 40 random sample sites to examine for statistically-significant ($p \leq 0.05$) differences in concentrations of groundwater quality constituents. Bicarbonate, calcium, SC-field, gross beta, hardness (**Figure 13**), magnesium, TDS, and TKN had concentrations that were higher in the hardrock aquifer compared to the alluvial aquifer; the opposite pattern occurred with temperature (**Figure 13**) and pH-field.

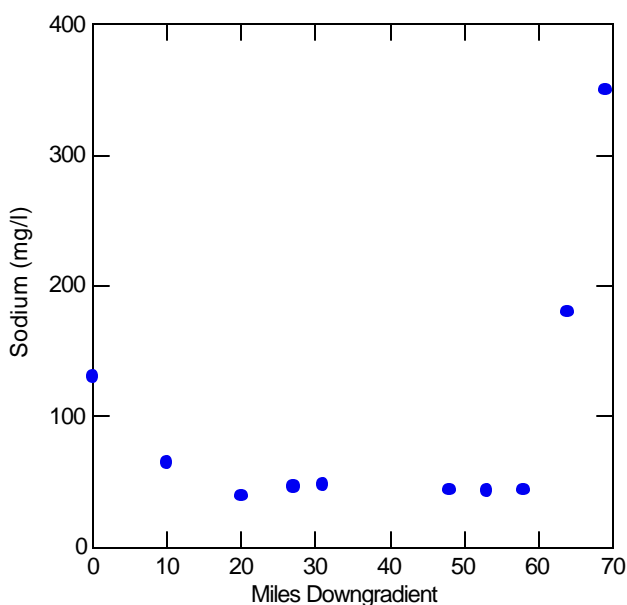
Geological Comparison - The four major geologic divisions in the SVGB, alluvial fill, granitic rock, metamorphic rock, and volcanic rock, were compared by applying the Kruskal-Wallis test in conjunction with the Tukey test to analyze results from the 40 random sample sites. These tests examined for statistically-significant ($p \leq 0.05$) differences in concentrations of groundwater quality constituents. Interpretation of groundwater data suggest the following six constituent concentration differences occur.

- < Calcium, gross alpha (**Figure 14**), hardness, SC-field, SC-lab, sulfate, and TDS concentrations were higher in groundwater associated with granitic rock than in alluvial fill and volcanic rock.
- < Bicarbonate (**Figure 14**) and total alkalinity concentrations were higher in groundwater associated with granitic rock than in groundwater associated with alluvial fill, volcanic rock, and metamorphic rock. Concentrations of these two constituents were also higher in groundwater associated with volcanic rock than in alluvial fill.
- < Gross beta and magnesium concentrations were higher in groundwater associated with granitic rock than in alluvial fill.
- < Fluoride levels were higher in groundwater associated with granitic than in volcanic rock.
- < Temperature was higher in groundwater associated with alluvial fill than in granitic rock and volcanic rock.
- < pH-field levels were higher in groundwater associated with alluvial fill and volcanic rock than in granitic rock.

Figure 11. Evolution in the Concentration of Major Cations along Groundwater Flowpath.

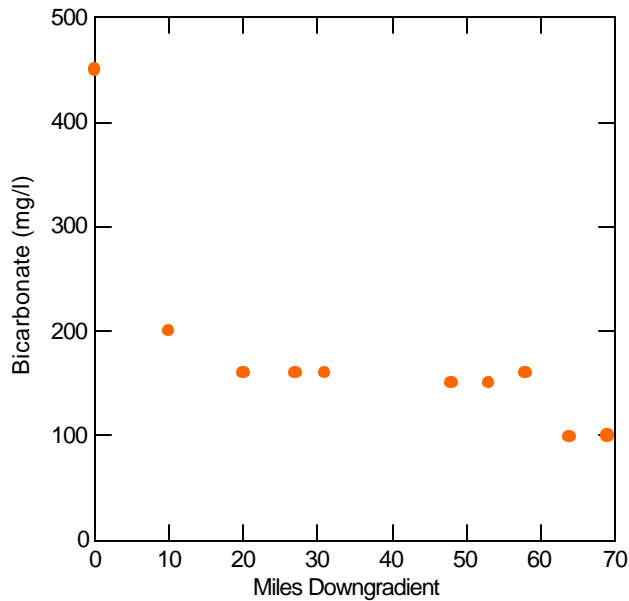


The graph to the left illustrates the variation in calcium concentrations along the groundwater flow path from upgradient to downgradient areas in the SVGB. Groundwater flow in the alluvial aquifer parallels the course of Sacramento Wash (30). Calcium concentrations generally decrease downgradient, magnesium follows a similar pattern. Calcium concentrations are typically high in recharge areas, either decreasing in basins containing more dilute waters or increasing depending on the availability of gypsum and halite within the alluvial fill (32).

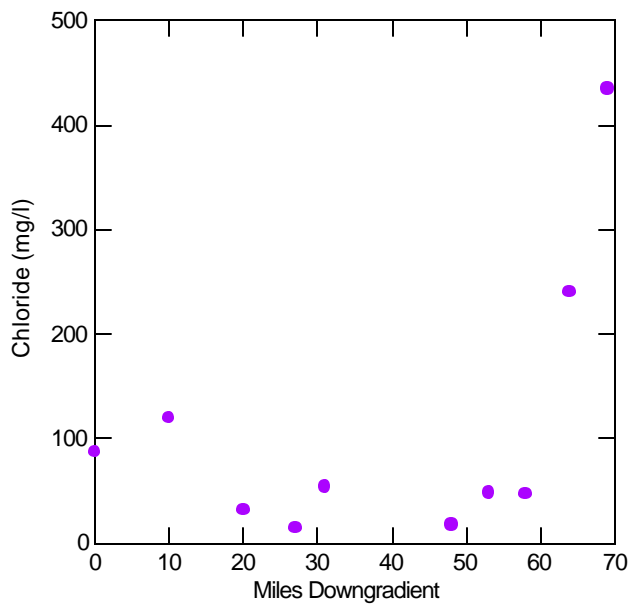


The graph to the left illustrates the variation in sodium concentrations along the groundwater flow path. On the graph, miles 2, 45, and 69 represent the communities of Chloride, Yucca, and Topock, respectively. Sodium concentrations initially decrease and then dramatically increase at the furthest downgradient sites. Constituents often correlated with sodium - pH, fluoride, and boron - had a similar pattern. Low concentrations of sodium are typically present in recharge areas; in downgradient areas sodium becomes the dominant cation probably as the result of silicate weathering and halite dissolution along

Figure 12. Evolution in the Concentration of Bicarbonate and Chloride along Flowpath.

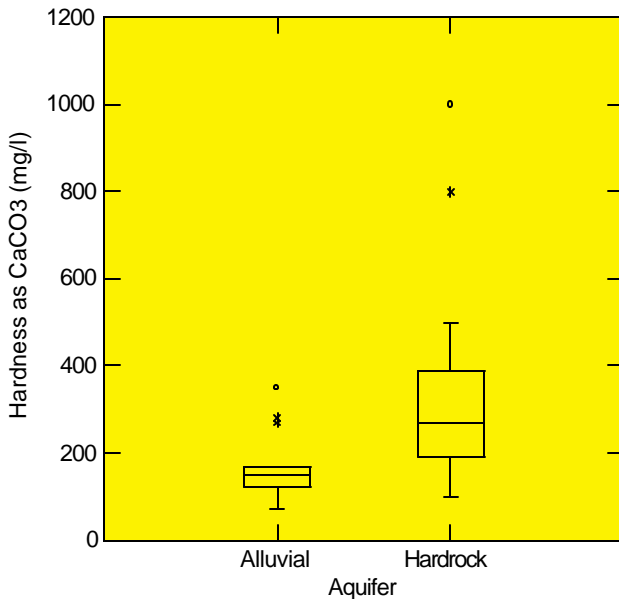


The graph to the left illustrates the variation in bicarbonate concentrations along the groundwater flow path from upgradient to downgradient areas in the SVGB. Groundwater flow in the alluvial aquifer parallels the course of Sacramento Wash (27). Bicarbonate decreases downgradient, especially after the first sample site which is located in an area of hardrock. Bicarbonate concentrations, along with calcium and magnesium, are frequently higher in recharge areas and

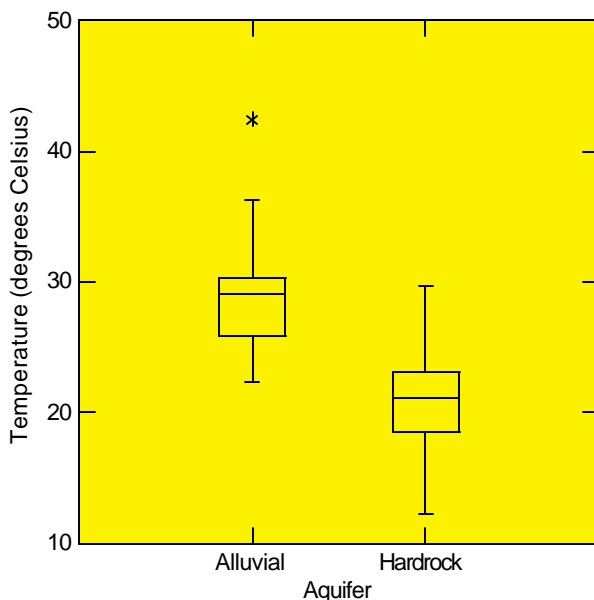


The graph to the left illustrates the variation in chloride concentrations along the groundwater flow path. On the graph, miles 2, 45, and 69 represent the communities of Chloride, Yucca, and Topock, respectively. Chloride concentrations initially decrease and then become highly elevated around Topock. Bicarbonate is frequently the dominant anion in recharge areas while chloride levels are low. Downgradient areas often evolve into a sodium-chloride chemistry as TDS levels increase (29). If chloride is the dominant anion, most commonly sodium is the predominant cation, and the water will

Figure 13. Hardness Concentrations and Temperature Levels Relative to Aquifers.

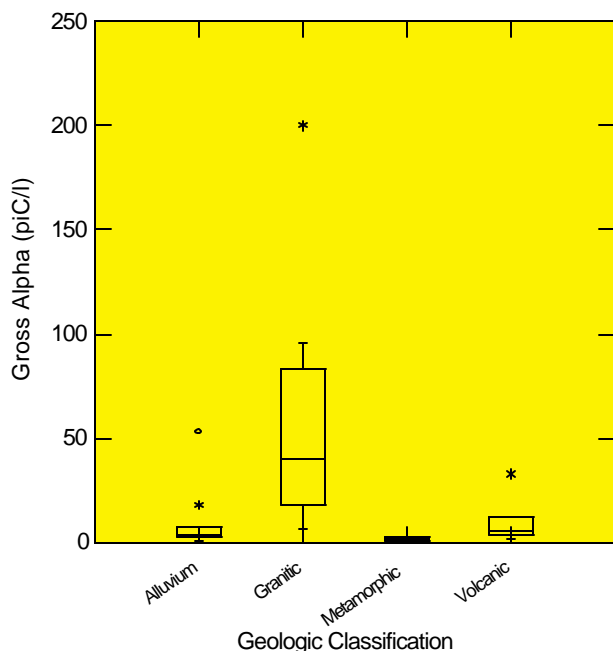


The boxplot to the left illustrates that hardness levels in the hardrock aquifer are higher than in the alluvial aquifer. Hardness concentrations between these aquifers were shown to be significantly different ($p \leq 0.05$) using a Kruskal-Wallis statistical test. Low-yield wells and springs in the mountains were found to have *hard* and *very hard* groundwater while high-yield wells in the valleys were *moderately hard*. This hardness difference may be due to the calcium- bicarbonate chemistry frequently associated with recharge areas as well as natural softening that often occurs in downgradient areas (29).

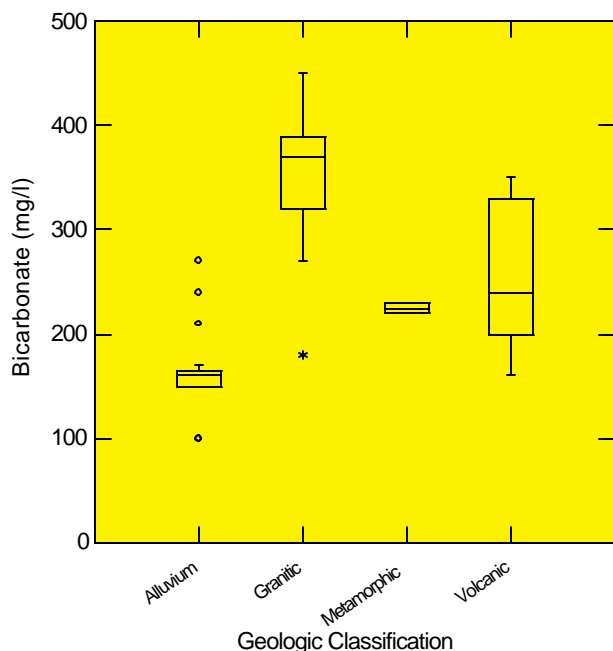


The boxplot to the left illustrates that temperature levels in the alluvial aquifer are frequently higher than those in the hardrock aquifer. Temperature levels between these aquifers were shown to be significantly ($p \leq 0.05$) different using a Kruskal-Wallis statistical test. This temperature difference is probably due to groundwater found at greater depths in the alluvial aquifer than in the hardrock aquifer. Groundwater temperatures have been reported to increase approximately 3 degrees Celsius with every 328 feet in depth (8). This alluvial-hardrock aquifer temperature difference has been found in several other Arizona groundwater

Figure 14. Concentrations of Gross Alpha and Bicarbonate Relative to Geologic Classification.



The boxplot to the left illustrates that gross alpha radiochemistry concentrations in granitic rock are higher than in alluvial fill, metamorphic rock, and volcanic rock. Gross alpha concentrations between these rock types were shown to be significantly ($p \leq 0.05$) different using Kruskal-Wallis and Tukey statistical tests. Radiochemistry levels are generally higher in low-yield, granitic hardrock wells (22). Most groundwater samples collected from wells located in granitic rock exceeded the 15 pCi/l Primary MCL for gross alpha. In the basin, granitic rock is typically found in the Cerbat



The boxplot to the left illustrates that bicarbonate concentrations in granitic rock are higher than in alluvial fill, metamorphic rock, and volcanic rock; concentrations in volcanic rock are also higher than in alluvial fill. Bicarbonate concentrations between these geologic classifications were shown to be significantly ($p \leq 0.05$) different using Kruskal-Wallis and Tukey statistical tests. High bicarbonate concentrations are often found in recharge areas (29). Precipitation and recharge in the SVGB are greatest in the Hualapai and Cerbat Mountains, both ranges are predominantly composed of

Sub-basin Comparison - The northern, upgradient portion of the SVGB and southern, downgradient portion of the basin (the town of Yucca was arbitrarily designated as the boundary between the northern and southern sub-basins) were compared by applying the Kruskal-Wallis test to analytical results collected from the 40 random sample sites. This test examined for statistically-significant ($p \leq 0.05$) differences in concentrations of groundwater quality constituents between these two sub-basin areas. Boron, fluoride (**Figure 15**), sodium, turbidity, and zinc concentrations were higher in the southern sub-basin than the northern sub-basin; the opposite pattern occurred with magnesium (**Figure 15**) concentrations.

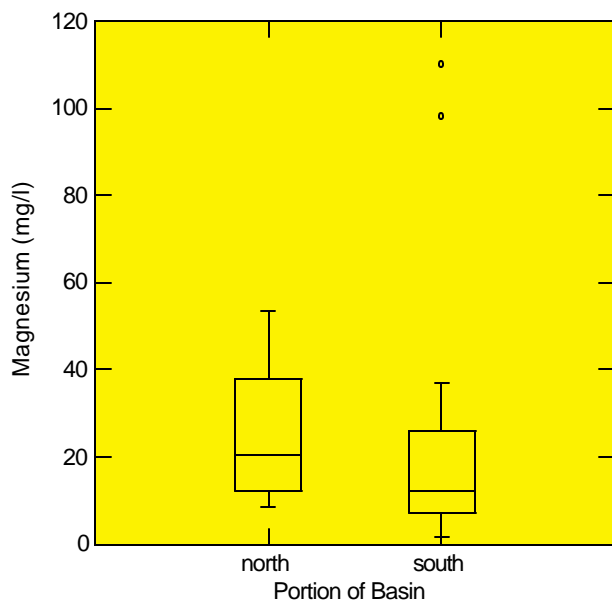
The eastern sub-basin encompasses areas to the east of Sacramento Valley Wash that are influenced by recharge from the Cerbat, Hualapai, and Mohave Mountains. The western sub-basin encompasses areas to the west of Sacramento Valley Wash that are influenced by recharge from the Black Mountains. These areas were compared by applying the Kruskal-Wallis test to analytical results collected from the 40 random sample sites. This test examined for differences in concentrations of groundwater quality constituents that were statistically-significant ($p \leq 0.05$). Boron, fluoride, gross alpha, pH-lab, sodium, sulfate (**Figure 16**), temperature, and zinc concentrations were significantly higher in areas east of Sacramento Valley Wash than in areas west of Sacramento Valley Wash. The opposite pattern was found for nitrate concentrations (**Figure 16**).

Groundwater Depth Comparison - The vertical variation of groundwater quality was examined by comparing constituent concentrations from 40 random sample sites to groundwater depth levels below land surface (bls) for statistically-significant ($p \leq 0.05$) correlations using regression analysis. Raw groundwater depth levels determined from field measurement or well-drilling records were used in this comparison. No other potentially important indices such as well depth or the depth of screened interval were considered. In the basin, many constituent concentrations tended to significantly decrease with increasing groundwater depth levels bls. Bicarbonate, boron, calcium, chloride, gross alpha, gross beta, hardness, sodium, SC-field, SC-lab, sulfate, total alkalinity (**Figure 17**), and TDS followed this pattern. Other constituents such as fluoride, magnesium, nitrate, TKN, and turbidity, while not statistically-significant ($p \leq 0.05$), also exhibited a trend of decreasing concentrations with increasing levels of groundwater depth bls. In contrast, pH-field and temperature (**Figure 17**) had levels that increased with increasing groundwater depth. Constituent concentrations from 16 random alluvial sites were also compared with groundwater depth for statistically-significant ($p \leq 0.05$) correlations using regression analysis. Calcium, chloride, gross beta, hardness, SC-field, SC-lab, and TDS had concentrations that decreased with increasing groundwater depth bls. In contrast, pH-field levels increased with increasing groundwater depth bls. Constituent concentrations from 24 random hardrock sites were also compared with groundwater depth for statistically-significant correlations ($p \leq 0.05$) using regression analysis. Boron, bicarbonate, sodium, and total alkalinity concentrations decreased with increasing groundwater depth bls. In contrast, temperature levels increased with increasing groundwater depth bls.

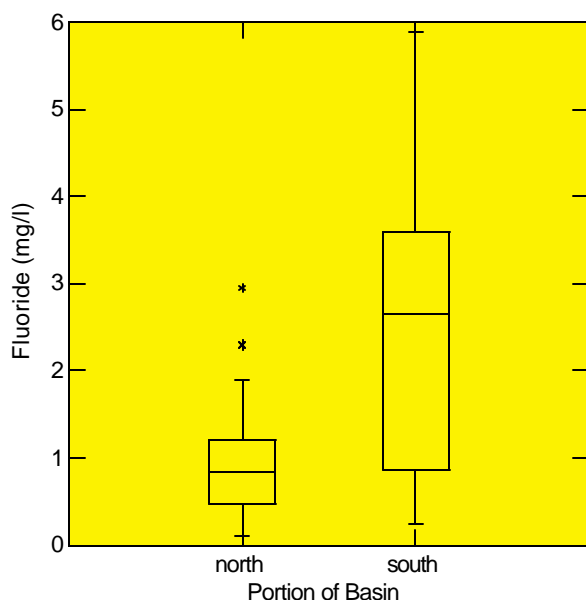
Groundwater Quality Time Trend Analysis

A time-trend analysis was conducted utilizing data collected by the U.S. Geological Survey (USGS) in 1979 (25), the Arizona Department of Water Resources (ADWR) in 1990 (27), and ADEQ in 1999. Fluoride, SC-field, and temperature were examined for changes over these 3 time periods in the same 14 wells. Only temperature levels varied significantly ($p \leq 0.05$), decreasing between 1990 and 1999. Thirteen (13) additional constituents - boron, calcium, chloride, hardness, magnesium, nitrate, pH-field, potassium, sodium, sulfate, total alkalinity, TDS, and zinc - were compared between the 1990 and 1999

Figure 15. Concentrations of Magnesium and Fluoride Relative to Upgradient and Downgradient Areas of the Basin.

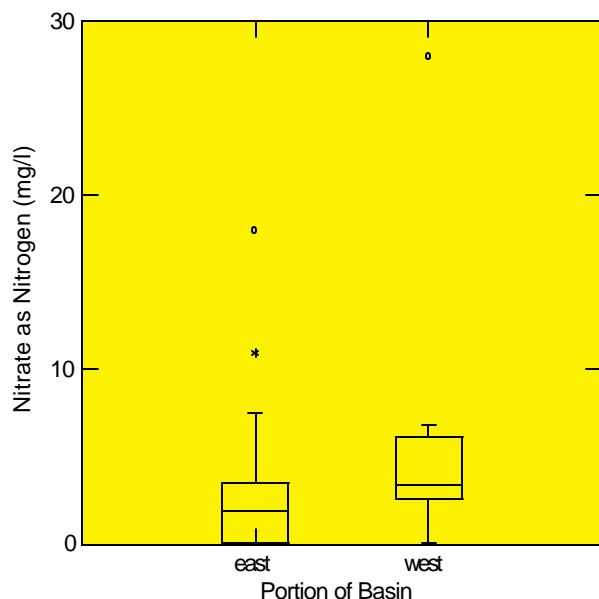


The boxplot to the left illustrates that magnesium concentrations in the northern portion of the SVGB are higher than in the southern portion. Magnesium concentrations between these sub-basins were shown to be significantly ($p \leq 0.05$) different using a Kruskal-Wallis statistical test. Groundwater flow in the SVGB is from north to south (27). Magnesium levels have been reported to decrease markedly downgradient in basins having

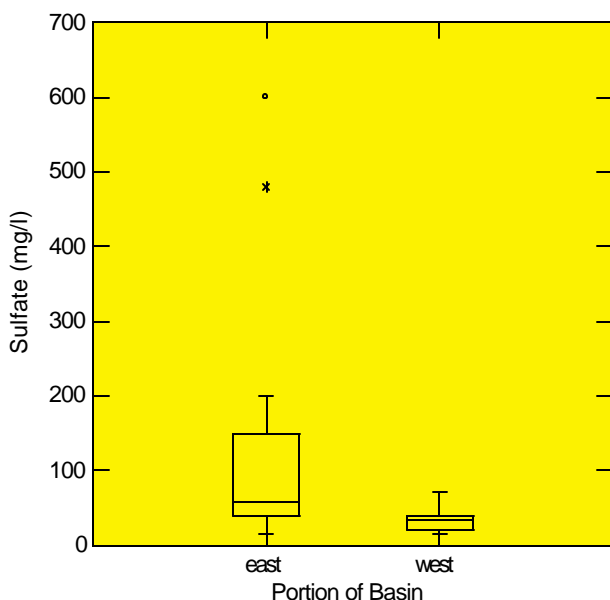


The boxplot to the left illustrates that fluoride concentrations in the southern portion of the SVGB are higher than in the northern portion. Fluoride concentrations between these sub-basins were shown to be significantly ($p \leq 0.05$) different using a Kruskal-Wallis statistical test. The boxplot illustrates that the median fluoride level in the southern sub-basin exceeds the Secondary MCL of 2 mg/l, and some sites even exceed the 4 mg/l Primary MCL. Fluoride levels are frequently low in recharge areas and increase with pH

Figure 16. Concentrations of Nitrate and Sulfate Relative to Eastern and Western Portions of the Basin.

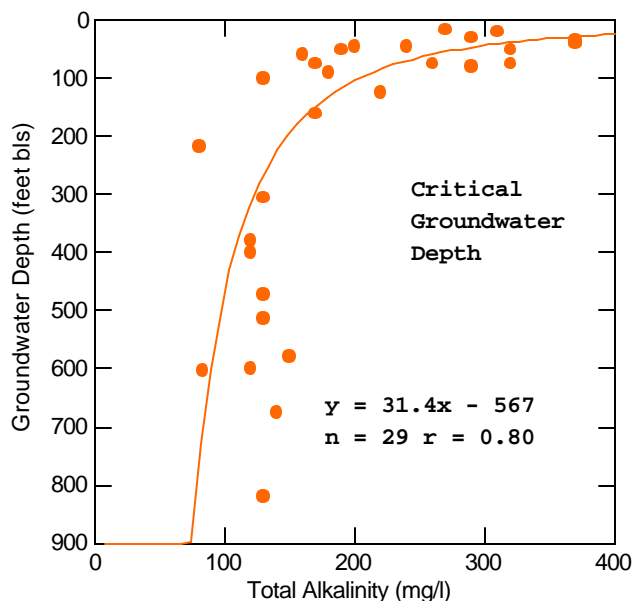


The boxplot to the left illustrates that nitrate concentrations to the west of Sacramento Wash are higher than to the east of this watercourse. Nitrate concentrations between these sub-basins were shown to be significantly ($p \leq 0.05$) different using a Kruskal-Wallis statistical test. The reasons for the nitrate variation are unclear. Nitrate concentrations are generally below Primary MCL water quality standards in the SVGB except in the Chloride area, where septic systems are used to process wastewater. In groundwater, nitrate is usually the only form of nitrogen of significance except in some reducing

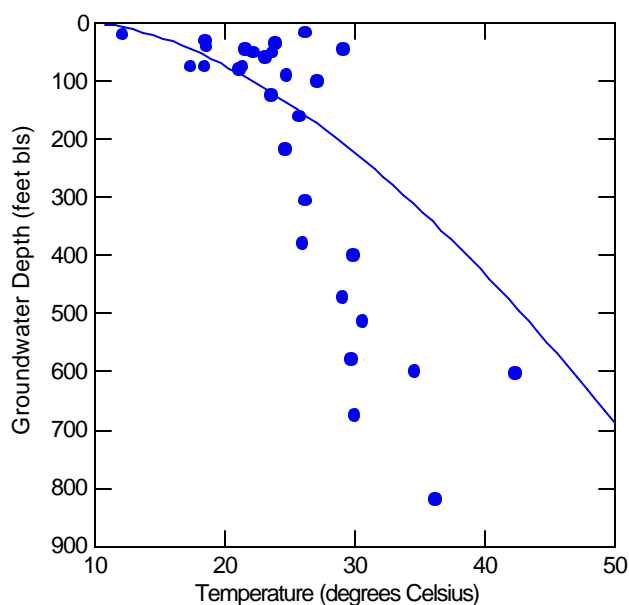


The boxplot to the left illustrates that sulfate concentrations to the east of Sacramento Wash are higher than to the west of this watercourse. Sulfate concentrations between these sub-basins were shown to be significantly ($p \leq 0.05$) different using a Kruskal-Wallis statistical test. Sulfate variations may be due to geological differences. The Cerbat and Hualapai Mountains to the east are mainly granitic, while the Black Mountains to west are predominantly volcanic. Sulfate groundwater concentrations in granitic rock can be up to three times greater than in

Figure 17. Total Alkalinity Concentrations and Temperature Levels as Biphasic Functions of Groundwater Depth



The graph to the left illustrates that total alkalinity concentrations tend to decrease with increasing groundwater depth bls. Regression shows this to be a significant ($p \leq 0.01$) biphasic relationship. Total alkalinity attains a *critical level* at approximately 175 feet bls. Total alkalinity concentrations remain generally constant at groundwater depths greater than the *critical level* and are highly variable at more shallow depths. Approximate *critical levels* for other constituents significantly correlated with groundwater depth ranged from 50 feet bls for gross alpha to 200 feet bls for TDS. Total alkalinity is a measurement of the acid-neutralizing capability of water (19).



The graph to the left illustrates that temperature levels tend to increase with increasing groundwater depth bls. Regression shows this to be a significant ($p \leq 0.01$) biphasic relationship. This positive correlation between temperature and groundwater depth was also found in the Douglas (38), Prescott AMA (37), Upper San Pedro (10), and Virgin River (39) groundwater basins in Arizona and has been reported by Robertson (29) as generally occurring within the state. Groundwater temperatures have been reported to increase approximately 3°

data in the same 14 wells. Only pH-field levels varied significantly ($p \leq 0.05$); increasing between 1990 and 1999. Interpretation of other data also suggest that groundwater quality in the basin has been stable over a much longer time period. Samples were collected in both 1967 and 1999 from a deep well (1,355 feet) with a groundwater depth of 820 feet in the old “Duval Well Field” in Golden Valley that supplies the Mineral Park mine (15). Concentrations of constituents, mainly major ions, are nearly identical in each sample despite the 32 years that separate their collection dates. The 1967 and 1999 parameter levels are provided for comparison (all units are in mg/l unless otherwise noted): calcium (32-37), magnesium (13-12), sodium (46-50), bicarbonate (162-160), sulfate (46-44.5), chloride (35-31.5), fluoride (0.8-0.6), hardness (132-150), SC (477-460 umhos/cm), and pH-field (7.7-7.67 su).

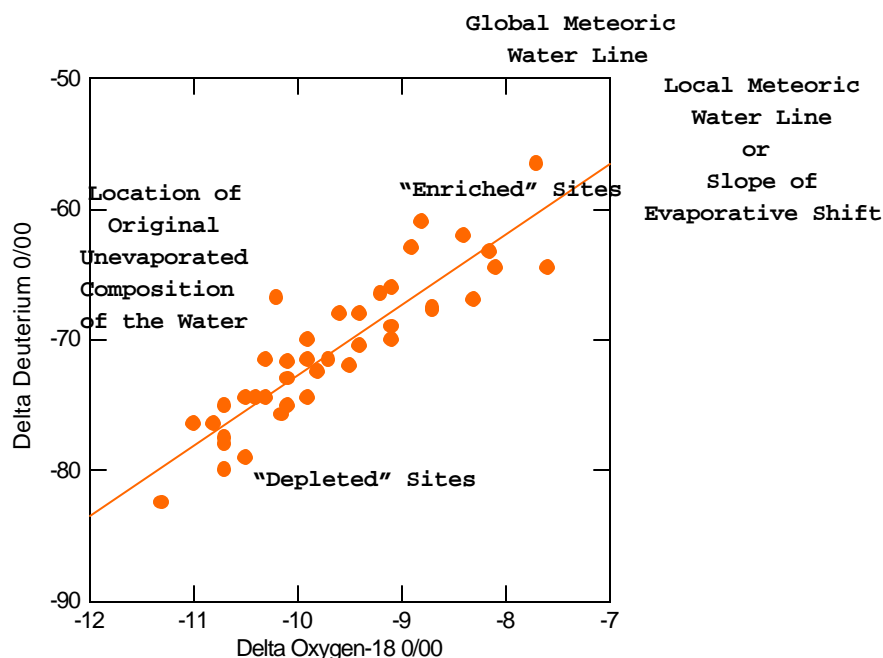
Groundwater Isotope Analysis

Deuterium and Oxygen - Groundwater characterizations may be made with respect to the climate and/or elevation where the water originated, residence within the aquifer, and whether or not the water was exposed to extensive evaporation prior to collection (12). These characterizations are done by comparing $d^{18}O$ and dD data to the Global Meteoric Water Line. The Global Meteoric Water Line (GMWL) is described by the linear equation (12): $dD = 8d^{18}O - 10$ where dD is deuterium in parts per thousand per mil (‰), 8 is the slope of the line, $d^{18}O$ is oxygen-18 ‰ , and 10 is the y-intercept. The GMWL is the standard by which water samples are compared and represents the best fit isotopic analysis of thousands of water samples from around the world. Isotopic data from a region may be plotted to create a Local Meteoric Water Line (LMWL) which is affected by varying climatic and geographic factors. When the LMWL is compared to the GMWL, inferences may be made about the origin or history of the local water (12).

The LMWL created by $d^{18}O$ and dD values for samples collected at sites in the SVGB, were compared to the GMWL. Most of the dD and $d^{18}O$ data lie below and to the right of the GMWL (**Figure 18**). Meteoric waters exposed to evaporation characteristically plot increasingly below and to the right of the GMWL. Evaporation tends to preferentially contain a higher percentage of lighter isotopes in the vapor phase and causes the water that remains behind to be isotopically heavier (14). Groundwater from arid environments is typically subject to evaporation which enriches dD and $d^{18}O$ resulting in a lower slope value (usually between 3 and 6) as compared to the slope of 8 associated with the GMWL (1). The data for the arid SVGB conform to this theory, having a slope of 5.5, with the LMWL described by the linear equation: $dD = 5.5d^{18}O - 18.2$. The intersection of the LMWL with the GMWL is thought to indicate the location of the original un-evaporated composition of the water.

$d^{18}O$ and dD values were compared by aquifer, geology, and sub-basin to examine for spatial differences. Using a Kruskal-Wallis test, no significant ($p \leq 0.05$) spatial differences were found in the $d^{18}O$ and dD values. Qualitatively, the sites most *enriched*, or isotopically heavier, were in scattered locations but often near the Black, McCracken, or Mohave Mountains. In contrast, the sites most *depleted*, or isotopically lighter were in scattered locations but often at springs or shallow wells located in or near the Hualapai or Cerbat Mountains. These depleted sites form a cluster near the GMWL that is the start of the evaporation trajectory. These springs may be from recent local precipitation and are less subject to evaporation than other sites in the basin. Interestingly, the most *depleted* site was at the deepest well (SV-44/45) in the basin located in Golden Valley and probably the result of a geothermal system at depth which tends to increase $d^{18}O$ values (14).

Figure 18. Values of Oxygen-18 and Deuterium at SVGB Sample Sites.



Values for δ oxygen-18 ($\delta^{18}\text{O}$) and δ deuterium (δD) in SVGB groundwater sample sites are shown above. The SVGB sites constitute a local meteoric water line ($\delta\text{D} = 5.5\delta^{18}\text{O} - 18.2$) that varies from the Global Meteoric Water Line or GMWL ($\delta\text{D} = 8\delta^{18}\text{O} - 10$). This was expected, since arid areas typically have slopes between 3 and 6. Conclusions from the SVGB isotope data are as follows:

- < The data plot below/to the right of the GMWL suggesting that the water has undergone a consequential amount of evaporation prior to recharge.
- < The data fit a line ($\delta\text{D} = 5.5\delta^{18}\text{O} - 18.2$) that has a slope less than the GMWL of 8, which is consistent with slopes of local meteoric water lines from other arid regions (12).
- < The isotopic data were compared by aquifer, geology, and sub-basin for spatial differences. There were no significant spatial variations among these indices.
- < Qualitatively, sites with isotopically enriched waters were scattered but often near the lower mountains (Black, McCracken, or Mohave) that have less precipitation and recharge. In contrast, sites with isotopically depleted waters often occur at springs or shallow wells in the higher mountains (Cerbat and Hualapai) that have more precipitation

$d^{18}\text{O}$ and $d\text{D}$ data from this study were compared to data collected by the U.S. Geological Survey (USGS) from groundwater sites in nearby basins along the Colorado River, as well as surface water sites along the river itself (29). Using ^{18}O and D isotopes, the USGS study was able to differentiate between groundwater originating from local recharge and groundwater originating from the Colorado River. Groundwater sites in the SVGB were within the range of $d^{18}\text{O}$ and $d\text{D}$ values that were provided for groundwater originating from local recharge in basins along the Colorado River. Thus, groundwater in the SVGB also probably originated from local recharge, though whether paleo or recent precipitation is unclear. Interestingly, the deepest SVGB groundwater sample collected (in Golden Valley from a 1355 feet deep well with an 820 foot water level) was isotopically similar to groundwater samples determined in the USGS study to be a mixture of Colorado River and local recharge. This raises the question whether and/or how recharge from the Colorado River could have potentially influenced the very deep groundwater in the SVGB. Perhaps in the distant past, the course of the Colorado River was through Detrital Valley and Sacramento Valley, exiting into the present-day course at Topock until uplift occurred and the river possibly changed course to its present location.

Nitrogen - A potential method for distinguishing sources of nitrate in groundwater is measuring two stable isotopes of nitrogen, nitrogen-14 and nitrogen-15, often represented by $d^{15}\text{N}$ (31). Although the percentage of the two isotopes is nearly constant in the atmosphere, certain chemical and physical processes often preferentially utilize one isotope, causing a relative enrichment of the other isotope in the remaining reactants. Because of these isotopic fractionation processes, nitrate from different nitrogen sources has been shown to have different N isotope ratios. The $d^{15}\text{N}$ values typically range from +2 to +8 per mil for natural soil organic matter sources, -3 to +2 per mil for fertilizer sources, +6 - +25 per mil for septic wastewater systems, and +9 to +25 per mil for animal waste. In a central California study, statistical analysis showed values from natural soil organic matter, septic systems, and animal sources were significantly different ($p=0.05$) from each other (31).

There appear to be multiple sources of nitrate occurring within groundwater within the SVGB. However, fertilizer does not appear to be a major nitrate source as there is an inconsequential amount of farmland in the basin. Sampling sites in the basin may be grouped according to the most likely nitrate source. This categorization of sampling sites is qualitative but usually relatively straightforward because of low level of development in the basin that usually precludes multiple sources of nitrate impacting the groundwater. Background natural soil organic sites appear to be represented by isolated wells, deep alluvial wells, and upgradient, springs in hardrock mountain areas. Animal sites appear to be represented by wells having adjacent corrals and used predominantly for stock watering. Septic system sites appear to be represented by wells which serve nearby domestic uses not connected to centralized sewer systems and which do not appear to have major impacts from animal sources. Nitrogen-15 levels were determined by contract laboratories for 39 sites in the SVGB. Seven sites had insufficient nitrate levels to conduct the isotope analysis and 1 site was not used because of QA/QC concerns. Results of $d^{15}\text{N}$ analytical analyses indicated that generally the SVGB data fell into published isotope spreads with 95% confidence levels of +4 to +10 for natural sources, +6 to +12 for septic sources, and +7 to +18 for animal sources. However, statistical analysis of the $d^{15}\text{N}$ data using the Kruskal-Wallis test in conjunction with the Tukey test revealed that the sources were not significantly ($p\#0.05$) different from one another, though the natural and animal sources narrowly missed being so ($p=0.059$).

SUMMARY AND CONCLUSIONS

Groundwater quality of the SVGB was assessed in 1999 by ADEQ. Sampling was conducted at 48 sites: 40 randomly selected and 8 targeted. Samples were collected at each site for analyses of SDW inorganic parameters, SDW VOCs, perchlorate, and isotopes of hydrogen, oxygen, and nitrogen and at most sites for SDW radiochemical analysis. Various groundwater quality concerns were examined in this study:

- < The suitability of groundwater for domestic or municipal uses.
- < The current (1999) baseline groundwater quality conditions.
- < The significant spatial and temporal groundwater quality patterns.
- < The methods of investigation and data evaluation for the study.

Suitability of Groundwater for Domestic and Municipal Uses

Comparisons of the groundwater quality data with SDW Primary and Secondary MCLs, as well as with the State of Arizona aquifer water-quality standards, indicate that samples from about half of the groundwater sites in the SVGB were suitable for domestic and municipal uses. Twenty-two (22) sites exceeded at least one health-based, Primary MCL constituent. Individual exceedances included gross alpha (18 sites), nitrate (6 sites), fluoride (4 sites), radium-226+228 (4 sites), and antimony (2 sites). Aesthetics-based Secondary MCLs were exceeded at 28 of 48 sites including TDS (24 sites), fluoride (16 sites), chloride (7 sites), sulfate (7 sites), manganese (3 sites), and iron (2 sites). Perchlorate, an inorganic salt which is very mobile in groundwater, was also detected at four sites. These findings support previous studies which indicate groundwater in the valley is generally of good chemical quality but is highly mineralized in and near the mountains, which often makes it unfit for human consumption (17). Despite these numerous SDW exceedances, large expanses of the basin had groundwater sampling sites that met water quality standards and provide a suitable source for drinking water purposes. Water quality exceedances are examined below by both geographic area and constituent.

Water quality standard exceedances in the SVGB were generally found in three specific areas:

- < Near the town of Chloride in the northern portion of the basin.
- < Near the Hualapai Mountains in the eastern portion of the basin.
- < Near the town of Topock in the extreme southwestern portion of the basin.

SDW Exceedances Near Chloride - In the Chloride area, all six groundwater sites sampled had constituents that exceeded at least one Primary MCL. Primary MCL exceedances occurred with gross alpha, nitrate, radium-226+228, and antimony; Secondary MCL exceedances occurred with TDS, chloride, sulfate, and manganese. These SDW exceedances are probably due to a combination of naturally high background levels, historic mining activity, and wastewater disposal using septic systems. Each potential source will be further explored below but the relative contribution of each source to the elevated constituent concentrations is beyond the scope of this study:

The highest gross alpha concentrations in the study area were near Chloride, located in the uppermost part of the basin on the western flank of the Cerbat Mountains. All six sites exceeded Primary MCLs, as gross alpha concentrations ranged from 73 pCi/l to 1100 pCi/l, the latter approximately 73 times greater than the Primary MCL. Three sites also exceeded the Primary MCL for radium 226+228, with 23 pCi/l the highest concentration. Elevated levels of gross alpha and radium-226+228 at sites near Chloride have been previously reported and may be naturally occurring because of the area's geology (6). The Cerbat Mountains are predominantly composed of granitic rock, which frequently is associated with elevated radiochemistry concentrations in groundwater (22). Gross alpha concentrations may be further elevated by the extensive hardrock mining that has occurred near Chloride, especially the dense cluster of inactive mines upgradient along Tennessee Wash (33). Parameters such as gross alpha and radium-226+228 are often elevated downgradient of mine tailing dumps because of the increased rock surface exposure (20). Other occurrences of elevated radiochemistry levels near historic mining activities have been documented near the town of Dos Cabezas in southeastern Arizona (36).

Historic mining activity also appears to impact the concentrations of sulfate, manganese, and antimony that sometimes exceed SDW quality standards. Ore deposits or hydrothermal deposits are probably the sources of sulfate in most Arizona basins (29). Although sulfur is not a major constituent of the earth's crust, it is widely distributed in reduced form in metallic sulfides. Concentrations of these sulfides often constitute ores of economic importance, and mining activity exposes greater amounts of rock surfaces to weathering. As a result of weathering and contact with water, the sulfides are oxidized to yield sulfate ions which are carried off in the water (18). Antimony and manganese are often elevated downgradient of mine tailing dumps (20). Antimony was rarely detected in the study, and levels near Chloride do not appear to be reflective of regional groundwater conditions. Previous targeted studies in the Chloride area found high mineralization in groundwater areas upgradient of town, but few detections of heavy metals occurred in wells located in town (32). In contrast, surface water sampling found high levels of arsenic, cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc apparently washed out of tailings (32). The most likely hypothesis for the limited detections of heavy metals is that there is limited groundwater flow from the upgradient, mining district east of Chloride to the town's aquifer (32). Factors such as different water elevations and lack of uniform seasonal water fluctuations seem to indicate that there is an abrupt transition separating the Cerbat Mountains from the alluvial fill of the SVGB, essentially creating separate aquifers. Sources indicate there could be a major fault in this area but because of the great thickness of alluvium, it is difficult to detect (15). The fixation of metals in soils and sediments, as well as the arid to xeric moisture regime, could play important auxiliary roles (33).

Elevated concentrations of nitrate, TDS, and chloride, which can be used as indicators for septic system impacts, were found at sites near Chloride. An interesting nitrate flowpath existed where the most upgradient sample had the lowest concentration (0.05 mg/l), two downgradient wells have concentrations below the Primary MCL (4.8 mg/l and 7.4 mg/l), and three further downgradient wells all exceeded the Primary MCL (15 mg/l, 18 mg/l, and 19 mg/l). TDS and chloride also increased markedly between sites upgradient of the town and sites within Chloride. These patterns indicate that the elevated concentrations of these constituents appear to be stemming from sources in Chloride. The numerous dry-lot subdivisions that use on-site septic systems for wastewater disposal are a likely source of nitrate, since agriculture and animal waste are minimal in this area (18). This conclusion was also reached by previous studies (32). The two soil types occurring in the Chloride area have different ratings for their use for septic tank absorption fields (26). The Barkerville-Gaddes-Rock outcrop association is composed of very shallow to moderately deep soils and rock outcrop on granitic mountains that has a *severe limitation* rating while the

Anthony-Vinton-Agua association is composed of deep soils on alluvial fans and low terraces that has a *slight limitation* rating (26). Many Chloride residences may have improper setback distances of wellheads from septic tank leach fields since much of the town was constructed before such regulations existed. Thus, groundwater in the area may be impacted by a high-density of septic systems predating existing codes in combination with local soil conditions that sometimes have severe limitations for septic system use.

SDW Exceedances Near the Hualapai Mountains - Primary MCL exceedances in the Hualapai Mountains occurred with gross alpha, radium-226+228, and fluoride; Secondary MCL exceedances occurred with TDS, fluoride, chloride, sulfate, iron, and manganese. Gross alpha exceedances are found in the granitic geology that stretches along the west flank of the Hualapai Mountains, except near Kingman where volcanic and metamorphic geology predominate (45). Granite rock often has elevated concentrations of radiochemistry constituents (22). Twelve of 13 sites within this area had gross alpha exceedances with concentrations ranging from 12 pCi/l to 96 pCi/l, the last site approximately six times greater than the Primary MCL. One site in this area also exceeded the radium 226+228 Primary MCL. Elevated fluoride concentrations were also found along the west flank of the Hualapai Mountains, south of Kingman. Fourteen of the 16 sites in this area exceeded the Secondary MCL, and two sites exceeded the Primary MCL for fluoride. The elevated fluoride concentrations may also be due to the area's granitic geology. Fluoride concentrations in groundwater collected from granitic rock have been found to be at least twice the concentration of those measured in other rock types (46). TDS, chloride, sulfate, manganese, and iron concentrations are particularly elevated in the vicinity of Groom Peak, perhaps due to localized geologic conditions. The two Secondary MCL exceedances for iron, as well as the only other two iron detections in the study area, occurred near Groom Peak though the source of iron at this location is unknown. In general, elevated concentrations of iron do not appear to be widespread in the study area.

SDW Exceedances Near Topock - The highest fluoride concentrations are found near Topock, located in the most downgradient area of the basin. Samples from two deep alluvial wells exceeded the Primary MCL for fluoride, including the highest concentration (5.9 mg/l) found in the study. Sources indicate calcium concentrations might be the most important control on higher fluoride concentrations (> 5 mg/l) through precipitation of the mineral fluorite (30). Relatively high concentrations of fluoride (> 4.5 mg/l) found at these two sites near Topock had corresponding and somewhat depleted concentrations of calcium that constitute less than 13 percent and 20 percent of the total cation concentration of each sample. These two sites also had moderately-alkaline groundwater (> 7.8 su). Previous studies have cited hydroxyl ion exchange or sorption-desorption reactions as providing controls on lower (< 5 mg/l) concentrations of fluoride (30). As pH values increase downgradient, greater levels of hydroxyl ions may effect an exchange of hydroxyl for fluoride ions thereby increasing the concentrations of fluoride in solution (30). TDS and chloride concentrations also exceeded the Secondary MCL near Topock and may be the result of dissolution reactions as the groundwater moves to downgradient areas, though the availability of gypsum and halite within the basin fill may also be an influence (29).

Other SDW Exceedances - The sample from the Mohave Mountains was collected from an unused well with a steel casing; the sulfate and manganese levels may not be indicative of actual groundwater conditions. The other two manganese exceedances occurred at sites in granitic areas. In general, elevated manganese levels do not appear to be reflective of the regional groundwater conditions.

Current (1999) Baseline Groundwater Quality Conditions

Regional groundwater in the basin may generally be described as *neutral* to *slightly alkaline* groundwater that is predominantly *fresh*, based on pH levels and TDS concentrations (18). Groundwater is frequently *very hard*, though many *hard* and *moderately hard* groundwater sites are found within the basin (13). Nitrate (as nitrogen) at about half the sites was reported to be at concentrations (> 3 mg/l) which *may indicate impacts from human activities* (23). Most trace elements such as antimony, barium, beryllium, cadmium, iron, lead, manganese, mercury, nickel, silver, and thallium were rarely detected in the basin. Only arsenic, boron, chromium, copper, fluoride, selenium, and zinc were detected at more than 10 percent of the sites at concentrations above ADHS Laboratory MRLs.

Perchlorate was detected at four sites within the basin. The presence of perchlorate in the SVGB may be related to occurrences of this man-made, inorganic salt sources in California, Nevada, and Utah, where nearly all the detections of perchlorate in groundwater have occurred to date (47). Large volumes of this compound have been disposed of since the 1950s in Nevada, California, and Utah, though up to 43 other states have facilities that have manufactured, used, or stored perchlorate (47). Perchlorate contamination of groundwater may be much greater than currently thought because of this compound's high solubility in water, its mobility in aqueous systems, and its high chemical stability (47).

Groundwater at half the sample sites is a calcium-bicarbonate type, which is both common in Arizona (36)(37)(38) and typical of recharge areas (29). Approximately a third of the sample sites, predominantly in hardrock areas, had a calcium-sulfate groundwater chemistry. Sulfate may become the dominant anion at these sites because of hardrock mining whose groundwater quality impacts include elevated concentrations of sulfate (20). Ore deposits or hydrothermal deposits are probably the sources of sulfate in most Arizona basins (29). Sodium-bicarbonate type water was found at six sites in alluvial areas, a groundwater chemistry common in downgradient areas (29). The two most downgradient sites exhibited sodium-sulfate type groundwater which is a common chemistry in downgradient areas when TDS levels increase (29). Two significant ($p \leq 0.05$) groundwater composition patterns emerged. A positive correlation existed among concentrations of calcium, magnesium, bicarbonate, sulfate, hardness, total alkalinity, and a negative correlation with temperature and pH-field. In contrast, a positive correlation existed among concentrations of sodium, chloride, sulfate, boron, and fluoride.

The groundwater flowpath paralleling the course of Sacramento Wash was examined to investigate whether the SVGB was an open or closed hydrologic system. Closed systems occur when the aqueous chemistry is determined solely by the reactions of the initial recharge waters with the various aquifer minerals and gases as the groundwater moves downgradient. In contrast, open systems occur when the groundwater chemistry is controlled or influenced by water or gases that enter the hydrologic system after the initial recharge (29). Constituent concentration variations along flowpaths appear to indicate that the SVGB is largely a closed system but is influenced in limited areas by downgradient recharge. The groundwater chemistry appears to be greatly affected by the lithology, mineralogy, and depositional environment of the alluvium. Length of time the alluvium has been in contact with water also has an effect on the level of dissolved cations and anions in the groundwater (27). Constituents such as calcium, magnesium, bicarbonate, hardness, and total alkalinity tend to have levels that decrease downgradient. In contrast, parameters such as sodium, chloride, fluoride, and boron tend to have levels that initially decrease, perhaps due to the dilution of the effects from mining in the northern portion of the basin, and then increase dramatically in downgradient areas.

Significant Spatial and Temporal Groundwater Quality Patterns

A critical factor in understanding regional groundwater quality is the ability to make comparisons among different areas (11). Groundwater quality in the SVGB was statistically examined for differences among aquifers, geology, and sub-basins, as well as with groundwater depth below land surface (bls), and over time. Significant ($p \leq 0.05$) patterns are discussed below:

Aquifer Comparison - Groundwater quality constituents such as bicarbonate, calcium, gross beta, hardness, magnesium, total alkalinity, SC-field, TDS, and TKN had significantly ($p \leq 0.05$) higher levels in the hardrock aquifer than in the alluvial aquifer. In contrast, two field parameters, pH and temperature, were significantly ($p \leq 0.05$) higher in the alluvial aquifer than in the hardrock aquifer. Similar significant ($p \leq 0.05$) alluvial-hardrock aquifer patterns have been found in other Arizona groundwater basins. These include pH and temperature in the Willcox basin (36), bicarbonate, calcium, hardness, magnesium, pH, temperature, and TDS in the Prescott AMA (37), and bicarbonate, calcium, hardness, magnesium, pH, and temperature in the Douglas basin (38). Previous studies in the SVGB have noted that groundwater along the base of the mountains tends to be highly mineralized, becoming less so towards the center of the valley (15). For example, a 1991 study found the highest TDS levels (1,400-2,400 mg/l) near the base of the Cerbat Mountains and the lowest levels (300-400 mg/l) were in the valley-floor alluvium (27). Several factors may contribute to the aquifer variation. The decrease in concentrations of some constituents as groundwater moves from hardrock areas to the valley alluvium may be due to precipitation reactions (29). The differences may also be influenced by different sources and quality of recharge. Alluvium recharge can partially be attributed to infiltration of streamflow, whereas recharge to hardrock aquifers is chiefly in direct response to precipitation events (33). Differences in pH levels are probably due to increases downgradient through silicate hydrolysis reactions that occur under closed aquifer conditions (30). Temperature differences are probably due to greater groundwater depth bls in the alluvial aquifer when compared to the hardrock aquifer. Groundwater temperatures typically increase with depth, approximately 3 degrees Celsius with every 328 feet after the relatively shallow *neutral zone* depth has been reached where shallow subsurface temperatures no longer vary seasonally (8).

Geology Comparison - The hardrock aquifer was subdivided into granitic, metamorphic, and volcanic geologic areas and groundwater quality comparisons were made among these geologic classifications and the alluvial fill. This geologic analysis revealed significant ($p \leq 0.05$) groundwater quality differences, particularly between granitic rock and alluvial fill. The previous hardrock-alluvial aquifer analysis masked several significant ($p \leq 0.05$) patterns, particularly involving granitic rock. Constituents such as bicarbonate, calcium, gross alpha, hardness, SC-field, SC-lab, sulfate, total alkalinity, and TDS had higher concentrations in the granitic rock than in the alluvial fill and volcanic rock. Bicarbonate and total alkalinity concentrations were also higher in volcanic rock than in alluvial fill. Gross beta and magnesium concentrations were higher in granitic rock than in alluvial fill. Fluoride concentrations were higher in granitic rock than in volcanic rock, a pattern also identified in other studies (44). Temperature levels were higher in alluvial fill than in granitic rock and volcanic rock. Levels of pH-field were higher in alluvial fill and volcanic rock than in granitic rock. Many of the constituent concentration differences between rock types, particularly the higher concentrations often found in granitic rock, have been cited in previous studies (44).

Sub-basin Comparison - Groundwater quality in the SVGB was found to vary significantly ($p \leq 0.05$) between the northern and southern ends of the basin, using the town of Yucca as a demarcation point.

Boron, fluoride, sodium, turbidity, and zinc concentrations were higher in the southern sub-basin than the northern sub-basin; the opposite pattern occurs with magnesium levels. Groundwater flow in the basin is from the north to south (27). In downgradient areas, such as the southern sub-basin, the dominant cation often evolves from calcium to sodium and concentrations of several trace elements also increase (32). Magnesium levels tend to decrease markedly along the flowpath in relatively dilute basin waters (29).

Significant ($p \leq 0.05$) differences in constituent concentrations exist between the eastern and western sub-basins using Sacramento Wash as the line of demarcation. Boron, fluoride, gross alpha, pH-lab, sodium, sulfate, temperature, and zinc concentrations were higher east of Sacramento Wash than west of the watercourse; the opposite pattern occurs with nitrate. These patterns may occur because of the previously noted predominance of granitic rocks in the eastern sub-basin as opposed to volcanic rocks to the west of the watercourse and their associated groundwater quality differences.

Groundwater Depth Comparison - Groundwater quality in the SVGB was also found to vary significantly ($p \leq 0.05$) with groundwater depth. Concentrations of bicarbonate, boron, calcium, chloride, gross alpha, gross beta, hardness, sodium, SC-field, SC-lab, sulfate, total alkalinity, and TDS decreased as groundwater depth increased bls. In contrast, temperature and pH-field had levels that increased with increasing groundwater depth bls. Many of these constituents are characterized by a *critical level* of groundwater depth. Constituent concentrations remain generally constant at groundwater depths greater than the *critical level* and are highly variable at more shallow depths. *Critical levels* in feet bls for constituents are as follows: bicarbonate (190), boron (180), calcium (150), chloride (110), gross alpha (50), gross beta (110), hardness (150), pH-field (200), sodium (300), SC-field (125), SC-lab (125), sulfate (100), total alkalinity (175), and TDS (200). Similar critical levels have also been found in other Arizona groundwater basins such as the Prescott AMA (37).

Similar significant ($p \leq 0.05$) parameter level-groundwater depth patterns have been found in other Arizona groundwater studies. These include bicarbonate, calcium, chloride, gross alpha, hardness, pH, sodium, SC, sulfate, temperature, total alkalinity, and TDS in the Willcox basin (36); bicarbonate, calcium, hardness, pH, SC, temperature, and TDS in the Prescott AMA (37); calcium, pH, and temperature in the Upper San Pedro basin (10); boron, calcium, hardness, pH, SC, sulfate, and temperature in the Douglas basin (38); bicarbonate, calcium, chloride, hardness, pH, sodium, SC, sulfate, temperature, total alkalinity, and TDS in the Virgin River basin (39); and calcium, hardness, sulfate, and total alkalinity in the Yuma basin (40). Previous studies in the SVGB also found TDS, bicarbonate, calcium, gross alpha, and gross beta concentrations decreased with increasing groundwater depth (29)(33). For example, radiochemistry samples from the Chloride town well were collected at four depths between 200 and 475 feet. Concentrations of gross alpha decreased from 161 to 36 pCi/l, gross beta decreased from 98 to 41 pCi/l but Ra-226+228 increased from 8 to 16 pCi/l (33).

Despite these many significant ($p \leq 0.05$) constituent concentration-groundwater depth relationships, other data suggest vertical (or groundwater depth) variation is less important than spatial variation for constituent concentrations in the SVGB. Groundwater depth is significantly ($p \leq 0.01$) greater in the alluvial aquifer than the hardrock aquifer. However, constituents tended to be significantly ($p \leq 0.05$) higher in the hardrock aquifer as compared to the alluvial aquifer. Thus, some of the groundwater depth patterns may be influenced by spatial patterns. This conclusion is supported by other investigators who indicate that in Arizona, groundwater constituent concentrations tend to be more a function of flow path evolution than of vertical mixing (29).

Time-Trend Comparisons - Groundwater quality was largely found to be stable over a period of up to 20 years with some constituents. A time-trend analysis was conducted utilizing data collected by the USGS in 1979, ADWR in 1990, and ADEQ in 1999. Three groundwater quality constituents, SC-field, fluoride, and temperature, were examined for changes among the three sampling episodes in the same 14 wells. Only temperature levels varied significantly ($p \leq 0.05$), decreasing between 1990 and 1999. The temperature decrease could be due to the season the sampling occurred rather than a change over time. The 1990 ADWR samples were collected in the summer; the 1999 ADEQ samples were collected in the winter. Groundwater passed through exposed steel plumbing at some sample sites, such as windmills, before a sample could be collected by field personnel. This plumbing factor, as well as normal seasonal temperature changes that occur in shallow groundwater, may have affected the measured temperature levels by heating and/or cooling the sample depending on when collection occurred. Thirteen (13) additional constituents - boron, calcium, chloride, hardness, magnesium, nitrate, pH-field, potassium, sodium, sulfate, total alkalinity, TDS, and zinc - were compared between the 1990 and 1999 data in the same 14 wells. Only pH-field levels varied significantly ($p \leq 0.05$), increasing between 1990 and 1999. The pH increase may be due to the different models of pH meters used in each study, rather than an actual change in the groundwater. Based on analysis of the groundwater quality data from these three different studies, constituent concentrations appeared relatively stable over this time period, and largely controlled by natural factors.

Methods of Investigation

Selection of groundwater sampling sites in this study utilized two strategies. A systematic, grid-based, random site-selection approach was used to investigate the regional groundwater quality; 40 samples were collected using this method. This number of sites to sample was determined by analyzing the variability of various parameter levels in historical Sacramento Valley groundwater quality data as well as administrative limitations on funding and personnel. Eight targeted samples were collected in areas where additional groundwater quality information was thought to be particularly valuable to the study.

Data Evaluation

Quality assurance (QA) procedures were followed and quality control (QC) samples were collected to ensure the validity of the groundwater quality data. Overall, the effects of sampling procedures and laboratory methods on the groundwater quality results were not considered significant. Analysis of equipment blank samples indicated systematic contamination of SC-lab, hardness, and turbidity; however, the extent of the contamination by these constituents was not considered significant. Analysis of standard reference samples by the ADHS laboratory during a previous study indicated a bias toward high concentrations of fluoride, magnesium, and zinc (10). Analysis of duplicate and split samples revealed excellent correlations; only turbidity and TKN analyses had wide median differences of 22 percent and 24 percent, respectively. Data validation was also examined in six QA/QC correlations that validated the acceptability of the groundwater quality data for further analysis. Data analysis for this study was conducted using Systat software. The normality of both the non-transformed data and the log-transformed data was determined by using the Kolmogorov-Smirnov one-sample test with the Lilliefors option (9). Spatial variations in constituent concentrations were investigated using the non-parametric Kruskal-Wallis test (17). Vertical (or groundwater depth) variations were examined using three regression models. Correlations among constituent concentrations were analyzed using the Pearson correlation coefficient test; changes over time were investigated using the Wilcoxon rank-sum test (17).

RECOMMENDATIONS

Recommendations for domestic well owners, public water supply systems, and future groundwater quality reports are provided in this section based on interpretations of the analytical results from groundwater samples collected for this study. The following recommendations are provided for domestic well owners in the SVGB:

- < ADEQ encourages well owners concerned about their water supply to periodically collect samples with the assistance of certified laboratories for analysis of the full range of SDW constituents. The ADHS, Environmental Laboratory Licensure and Certification Section at (602) 255-3454 provides a list of certified laboratories.
- < Well owners interested in less expensive and more targeted testing of their water source should include in their sampling and analysis the following constituents: gross alpha, nitrate, and fluoride. Those in the Chloride area should test for gross alpha and nitrate, those in the Hualapai Mountains should test for gross alpha and fluoride, and those in the Topock area should test for fluoride.
- < ADEQ encourages well owners to inspect and, if necessary, repair faulty surface seals, degraded casing, or other factors that may affect well integrity. Septic systems should also be inspected periodically to assure safety and compliance with ADEQ's *Engineering Bulletin #12* (2).

The following recommendations are provided for public water systems within the SVGB:

- < Groundwater quality data collected during this study should assist in the site selection process of new public supply wells. Groundwater samples at some sites exceeded SDW standards and caution should be used in the site selection process in developing new public water supplies, particularly in the Chloride, Hualapai Mountain, and Topock areas.
- < Groundwater sites where groundwater recharge appears to be occurring could be further examined as potential sites for future artificial recharge projects.

The following recommendations are provided for future groundwater quality studies within the SVGB:

- < Resampling of the ADEQ index wells appears to be unnecessary at intervals of less than approximately ten years. The time-trend analysis indicates that constituent concentrations did not significantly ($p \leq 0.05$) change between 1990 and 1999. This suggests that most of the constituents are largely controlled by natural factors and are not prone to vary significantly over time in the near term.
- < A comprehensive, targeted groundwater-surface water study should be conducted in the Chloride area to determine the source and extent of elevated constituent concentrations with the focus on defining areas where future public water supply wells should be located.
- < Individual flow paths could be examined to better understand the specific geochemical reactions occurring within the study area.

- < Wastewater disposal practices appear to be impacting groundwater quality in the SVGB. Critical evaluations, especially the number, density, and soil type of septic systems in certain areas should be conducted prior to installation of new wastewater systems. A large number of residential septic systems have been installed in the Golden Valley area over the past 10 years. It is anticipated that continued installation of wastewater disposal systems will occur into the future (24). Septic systems are also the frequent means of wastewater disposal in Kingman, including some densely-populated subdivisions built on fractured bedrock (24). Representatives of the Mohave County Department of Health and Social Services have expressed concern to ADEQ that recent nitrate SDW Primary MCL exceedances in wells in the Kingman area are most probably related to discharges from the many septic systems (24). This problem will most likely increase in the future.

The following recommendations for future groundwater quality studies utilizing isotope sampling are:

- < This study is the first widespread application of stable isotopes in characterizing regional groundwater by the ADEQ Groundwater Monitoring Unit and was partially intended to test the usefulness of this technology. Analyses of deuterium and oxygen-18 isotopes appear to be of greatest value for regional studies where there is a need to trace interactions between groundwater and surface water. Sampling for deuterium and oxygen-18 isotopes might be useful in specific groundwater basins in order to differentiate between recharge originating from a major river (or surface water such as the Central Arizona Project applied for irrigation purposes) compared with recharge originating from local sources. Analyses of this type would assist in distinguishing between fresh water originating from river infiltration and paleowater representing a non-renewable resource.
- < This study also evaluated the use of nitrogen isotopes as a tool for identifying nitrate contamination sources in regional groundwater basin studies in Arizona. This is an important application because nitrate levels typically vary considerably with location in these studies, owing to differing land uses, geochemical processes, as well as other factors. Identifying the source of nitrogen through the use of isotopes would be an invaluable asset. The $d^{15}N$ values determined from the various sites in this study generally fall within the range of values reported for the various nitrogen sources in the literature. However, enough outliers were present to suggest it is not possible to fingerprint the source of nitrate contamination simply by measuring the $d^{15}N$ value and qualitatively determining the major source of nitrogen at each site. Previous studies have stressed the necessity of measuring the $d^{15}N$ of specific suspected sources of nitrate contamination for the area of interest, as using values from the literature may not be specific enough to clearly separate source types (31). Accessing wells which specifically measure the $d^{15}N$ isotopic signature of each potential source of nitrate is rarely possible in regional studies. Other potential problems in using nitrogen isotopes to fingerprint nitrate sources include multiple sources of nitrogen that are hard to interpret. Denitrification may also occur, especially with shallow groundwater, which would raise $d^{15}N$ values above those of the original source. Thus, nitrogen isotopes appear to have limited value in regional studies, a conclusion reached in other reports (35). Sampling for nitrogen isotopes could be potentially useful in groundwater research targeted at specific nitrate problem areas or in a regional study which seeks to differentiate nitrate sources with highly different nitrogen isotopic signatures such as fertilizers and animal sources, and/or natural and septic sources.

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Appendix A. Groundwater Quality Data, SVGB, 1999

Site #	ADEQ #	Temperature (°C)	pH-field (su)	SC-field (FS/cm)	SC-lab (FS/cm)	TDS (mg/l)	Hardness (mg/l)	Turbidity (ntu)
SV-01	57599	21.58	7.73	829	680	430	260	0.11
SV-02	57746	23.59	7.35	674	650	420	220	0.34
SV-03	48679	17.37	7.55	502	430	300	190	0.14
SV-04/05	57747	21.18	7.45	873	780	490	390	0.15
SV-06	57745	18.60	7.40	1471	1300	890	500	0.21
SV-07	48705	23.15	7.50	1040	980	630	370	0.12
SV-09	21921	20.78	7.68	373	360	230	190	0.13
SV-10	57744	18.52	7.25	1248	1100	750	500	0.01
SV-13	57779	25.75	7.29	628	540	360	150	0.06
SV-15	21793	18.13	7.49	510	380	270	120	0.17
SV-16	57782	34.58	7.63	398	390	280	140	0.04
SV-17/20	57781	27.74	7.03	995	905	595	350	2.19
SV-18	57784	30.58	8.01	347	330	220	86	0.12
SV-21/22	21387	22.22	7.18	1456	1245	847	480	0.01
SV-23	57785	23.95	6.96	809	690	450	280	3.9
SV-24/25/26	57955	24.70	8.00	1266	1100	670	125	0.43
SV-27	48451	26.24	7.90	575	520	390	160	0.76
SV-28	57954	29.74	7.94	469	450	280	170	0.05
SV-29/30	21174	21.70	7.44	478	400	290	140	0.03
SV-31	21572	16.27	7.13	834	630	410	250	6.2
SV-32	57952	15.72	8.26	875	650	440	310	3.4
SV-33	57826	21.36	7.41	1345	1100	720	320	7.8
SV-34	57934	19.99	6.91	2360	2700	1900	900	1.0
SV-35	57935	12.19	7.67	1019	1000	630	100	0.50
SV-36	57936	26.21	7.67	910	900	550	110	12
SV-37	57937	23.68	7.61	537	540	330	230	0.42
SV-38	57942	21.51	7.03	1346	1400	830	490	4.2
SV-39	57943	22.21	6.87	2560	2700	1800	1000	0.40

bold = parameter level exceeds Primary or Secondary MCL

Appendix A. Groundwater Quality Data, SVGB, 1999--Continued

Site #	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Bicarbonate (mg/l)	Chloride (mg/l)	Sulfate (mg/l)
SV-01	71	22	48	6.7	290	38	33
SV-02	72	11	68	2.1	270	51	40
SV-03	53	13	26	7.5	210	24	20
SV-04/05	77.5	47	30	5.1	350	71	40.5
SV-06	110	49	130	8.0	450	80	200
SV-07	110	26	64	6.2	200	120	70
SV-09	50	17	12	2.0	200	13	14
SV-10	140	38	73	2.5	350	91	180
SV-13	41	11	67	2.4	210	51	33
SV-15	37	9.9	30	1.6	160	25	20
SV-16	35	14	33	5.3	150	27	36
SV-17/20	110	20	60.5	3.4	240	97.5	86
SV-18	22	8.3	46	5.1	160	14	15
SV-21/22	102.5	53.5	102	3.15	455	90	180.5
SV-23	78	21	52	1.6	320	44	57
SV-24/25/26	42.5	4.75	180	5.35	99	240	74.5
SV-27	32	20	48	4.6	160	54	41
SV-28	29	22	36	5.4	180	31	35
SV-29/30	36	11	30	6.9	160	25	20
SV-31	62	24	30	6.1	180	64	43
SV-32	59	39	27	4.0	330	39	31
SV-33	79	28	140	5.0	320	110	160
SV-34	240	74	280	7.4	410	390	570
SV-35	32	5.7	210	2.9	380	76	85
SV-36	37	3.6	180	5.5	330	80	76
SV-37	81	8.1	28	5.3	230	24	28
SV-38	130	35	110	3.7	300	240	110
SV-39	220	110	220	13	390	420	480

bold = parameter level exceeds Primary or Secondary MCL

Appendix A. Groundwater Quality Data, SVGB, 1999–Continued

Site #	Nitrate-Nitrite-N (mg/l)	Nitrate - N (mg/l)	Nitrite-N (mg/l)	TKN (mg/l)	Ammonia-N (mg/l)	Phosphorus (mg/l)
SV-01	0.12	0.12	ND	ND	ND	ND
SV-02	4.5	4.5	ND	ND	ND	0.058
SV-03	3.5	3.5	ND	ND	ND	ND
SV-04/05	1.35	1.35	ND	ND	ND	ND
SV-06	18	18	ND	0.39	0.035	ND
SV-07	28	28	ND	0.16	0.029	ND
SV-09	2.6	2.6	ND	0.097	0.021	0.022
SV-10	4.8	4.8	ND	0.15	ND	ND
SV-13	3.2	3.2	ND	ND	ND	0.024
SV-15	3.4	3.4	ND	0.08	ND	0.031
SV-16	2.6	2.6	ND	ND	ND	ND
SV-17/20	11	11	ND	ND	ND	ND
SV-18	2.8	2.8	ND	ND	ND	ND
SV-21/22	0.083	0.083	ND	0.077	ND	ND
SV-23	ND	ND	ND	ND	ND	ND
SV-24/25/26	2.2	2.2	ND	ND	ND	ND
SV-27	2.4	2.4	ND	ND	ND	ND
SV-28	0.52	0.52	ND	ND	ND	ND
SV-29/30	6.1	6.1	ND	ND	ND	ND
SV-31	6.8	6.8	ND	0.10	ND	ND
SV-32	1.9	1.9	ND	0.21	ND	ND
SV-33	0.086	0.086	ND	0.069	ND	ND
SV-34	0.73	0.73	ND	0.21	ND	ND
SV-35	5.8	5.8	ND	0.17	ND	ND
SV-36	1.2	1.2	ND	0.099	ND	ND
SV-37	7.1	7.1	ND	ND	ND	ND
SV-38	0.99	0.99	ND	0.072	ND	ND
SV-39	0.93	0.93	ND	0.13	ND	ND

bold = parameter level exceeds Primary or Secondary MCL

ND = Not detected above the minimum reporting level

Appendix A. Groundwater Quality Data, SVGB, 1999–Continued

Site #	Aluminum (mg/l)	Antimony (mg/l)	Arsenic (mg/l)	Barium (mg/l)	Beryllium (mg/l)	Boron (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Copper (mg/l)
SV-01	ND	ND	ND	ND	ND	0.14	ND	ND	ND
SV-02	ND	ND	ND	ND	ND	0.11	ND	ND	ND
SV-03	ND	ND	ND	ND	ND	ND	ND	ND	ND
SV-04/05	ND	ND	ND	ND	ND	ND	ND	ND	ND
SV-06	ND	ND	ND	ND	ND	0.35	ND	ND	ND
SV-07	ND	ND	ND	ND	ND	0.23	ND	ND	ND
SV-09	ND	ND	ND	ND	ND	ND	ND	ND	ND
SV-10	ND	ND	ND	ND	ND	0.18	ND	ND	ND
SV-13	ND	ND	0.012	ND	ND	0.14	ND	ND	ND
SV-15	ND	ND	ND	ND	ND	ND	ND	ND	ND
SV-16	ND	ND	ND	ND	ND	0.18	ND	ND	ND
SV-17/20	ND	ND	ND	ND	ND	0.18	ND	ND	0.025
SV-18	ND	ND	ND	ND	ND	ND	ND	0.019	ND
SV-21/22	ND	ND	ND	ND	ND	0.18	ND	ND	ND
SV-23	ND	ND	ND	ND	ND	0.12	ND	ND	ND
SV- 24/25/26	ND	ND	ND	ND	ND	0.615	ND	ND	ND
SV-27	ND	ND	ND	ND	ND	0.16	ND	0.033	ND
SV-28	ND	ND	ND	ND	ND	0.14	ND	0.017	ND
SV-29/30	ND	ND	ND	ND	ND	0.12	ND	ND	ND
SV-31	ND	ND	ND	ND	ND	0.14	ND	ND	ND
SV-32	ND	ND	ND	ND	ND	0.11	ND	ND	ND
SV-33	ND	ND	ND	ND	ND	0.18	ND	ND	ND
SV-34	ND	ND	0.011	ND	ND	0.38	ND	ND	0.013
SV-35	ND	ND	ND	ND	ND	0.60	ND	ND	0.019
SV-36	ND	ND	ND	ND	ND	0.54	ND	ND	ND
SV-37	ND	ND	ND	ND	ND	0.14	ND	ND	ND
SV-38	ND	ND	ND	ND	ND	0.28	ND	ND	ND
SV-39	ND	ND	ND	ND	ND	0.49	ND	ND	ND

bold = parameter level exceeds Primary or Secondary MCL

ND = Not detected above the minimum reporting level

Appendix A. Groundwater Quality Data, SVGB, 1999--Continued

Site #	Fluoride (mg/l)	Iron (mg/l)	Lead (mg/l)	Manganese (mg/l)	Mercury (mg/l)	Selenium (mg/l)	Silver (mg/l)	Thallium (mg/l)	Zinc (mg/l)
SV-01	0.48	ND	ND	ND	ND	ND	ND	ND	ND
SV-02	0.74	ND	ND	ND	ND	ND	ND	ND	ND
SV-03	0.49	ND	ND	ND	ND	ND	ND	ND	0.47
SV-04/05	1.2	ND	ND	ND	ND	ND	ND	ND	0.25
SV-06	1.9	ND	ND	ND	ND	ND	ND	ND	ND
SV-07	0.92	ND	ND	ND	ND	0.0061	ND	ND	ND
SV-09	ND	ND	ND	ND	ND	ND	ND	ND	ND
SV-10	1.1	ND	ND	ND	ND	0.006	ND	ND	ND
SV-13	0.47	ND	ND	ND	ND	ND	ND	ND	0.13
SV-15	0.4	ND	ND	ND	ND	ND	ND	ND	0.057
SV-16	1.3	ND	ND	ND	ND	ND	ND	ND	0.36
SV-17/20	2.95	ND	ND	ND	ND	0.0081	ND	ND	0.089
SV-18	0.65	ND	ND	ND	ND	ND	ND	ND	0.085
SV-21/22	2.3	ND	ND	ND	ND	ND	ND	ND	ND
SV-23	2.3	ND	ND	ND	ND	ND	ND	ND	ND
SV-24/25/26	4.55	ND	ND	ND	ND	ND	ND	ND	ND
SV-27	0.95	ND	ND	ND	ND	ND	ND	ND	ND
SV-28	1.2	ND	ND	ND	ND	ND	ND	ND	0.29
SV-29/30	0.37	ND	ND	ND	ND	ND	ND	ND	ND
SV-31	0.55	ND	ND	ND	ND	ND	ND	ND	ND
SV-32	0.44	ND	ND	ND	ND	ND	ND	ND	ND
SV-33	3.2	0.42	ND	ND	ND	ND	ND	ND	0.22
SV-34	1.8	0.10	ND	ND	ND	0.01	ND	ND	0.062
SV-35	5.7	ND	ND	ND	ND	ND	ND	ND	0.29
SV-36	1.6	ND	ND	ND	ND	ND	0.0058	ND	0.58
SV-37	0.51	ND	ND	ND	ND	ND	ND	ND	0.41
SV-38	2.1	ND	ND	ND	ND	ND	0.0058	ND	0.75
SV-39	2.3	ND	ND	ND	ND	ND	0.0081	ND	0.97

bold = parameter level exceeds Primary or Secondary MCL

ND = Not detected above the minimum reporting level

Appendix A. Groundwater Quality Data, SVGB, 1999–Continued

Site #	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Ra-226+228 (pCi/L)	Uranium (ug/l)	Perchlorate (mg/l)	d D (‰)	d ¹⁵ N (‰)	d ¹⁸ O (‰)	SDW VOCs (ug/l)
SV-01	-	-	-	-	ND	-71.5	8.39	-9.7	ND
SV-02	5.2+/-1.1	< LLD	< LLD	-	ND	-72.5	1.61	-9.8	ND
SV-03	3.7+/-0.7	7.1+/-0.96	-	-	ND	-70.0	2.82	-9.1	ND
SV-04/05	12+/-1.8	6.9+/-1.0	< LLD	-	ND	-67.0	17.57	-8.3	ND
SV-06	6.4+/-0.74	11+/-1.1	< LLD	-	ND	-67.5	18.07	-8.7	ND
SV-07	-	-	-	-	0.0058	-64.5	5.58	-7.6	ND
SV-09	-	-	-	-	ND	-70.5	3.54	-9.4	ND
SV-10	73+/-1.7	39+/-1.5	7.8+/-1.1	56 +/-4	ND	-71.5	7.65	-10.3	ND
SV-13	2.1+/-0.78	1.4+/-0.84	-	-	ND	-77.5	10.51	-10.7	ND
SV-15	1.8+/-0.64	9.1+/-0.94	-	-	0.006	-68.0	6.98	-9.4	ND
SV-16	< LLD	2.9+/-0.84	-	-	ND	-73.0	6.28	-10.1	ND
SV-17/20	18+/-0.76	4.9+/-1.0	< LLD	27+/-3.2	ND	-67.75	6.47	-8.7	ND
SV-18	2.6+/-0.66	4.4+/-0.86	-	-	0.021	-71.5	7.58	-9.9	ND
SV-21/22	40+/-1.1	12+/-1.1	< LLD	77+/-6.2	ND	-75.0	INS	-10.1	ND
SV-23	22+/-1.8	7.2+/-0.96	< LLD	25+/-2.2	ND	-80.0	INS	-10.7	ND
SV-24/25/26	7.4+/-0.63	5.8+/-1.2	-	-	ND	-72.3	5.29	-10.0	ND
SV-27	3.5+/-0.86	5.1+/-0.94	-	-	ND	-70.0	5.4	-9.9	ND
SV-28	5.4+/-0.94	6.6+/-0.94	< LLD	-	ND	-78.0	INS	-10.7	ND
SV-29/30	1.5+/-0.58	6.8+/-0.96	-	-	ND	-63.25	2.18	-8.15	ND
SV-31	-	-	-	-	ND	-72.0	3.37	-9.5	ND
SV-32	-	-	-	-	ND	-64.5	3.12	-8.1	ND
SV-33	-	-	-	-	ND	-79.0	INS	-10.5	ND
SV-34	30+/-1.6	18+/-1.7	< LLD	67+/-5.6	ND	-69.5	21.13	-9.4	ND
SV-35	33+/-1.7	18+/-1.2	< LLD	67+/-5.2	0.015	-62.0	9.38	-8.4	ND
SV-36	33+/-1.4	18+/-1.3	< LLD	48+/-4.4	ND	-66.5	13.23	-9.2	ND
SV-37	0.93+/-0.6	6.2+/-0.58	-	-	ND	-63.0	6.25	-8.9	ND
SV-38	-	-	-	-	ND	-72.0	5.43	-9.9	ND

bold = parameter level exceeds Primary or Secondary MCL
INS=Insufficient N for analysis

LLD = Lower Limit of Detection
ND = Not detected above the minimum reporting level

Appendix A. Groundwater Quality Data, SVGB, 1999--Continued

Site #	ADEQ #	Temperature (°C)	pH-field (su)	SC-field (FS/cm)	SC-lab (FS/cm)	TDS (mg/l)	Hardness (mg/l)	Turbidity (ntu)
SV-40	57944	21.90	6.77	4630	5200	3700	1900	2.4
SV-41	57945	18.46	7.05	1890	1900	1400	800	12
SV-42	57946	18.57	7.12	1256	1300	830	390	0.15
SV-43	57947	12.64	7.56	934	970	630	380	2.6
SV-44/45	57948	36.22	7.67	457	460	305	150	0.12
SV-46	57949	22.31	7.49	879	900	540	270	6.1
SV-48	57820	18.67	7.19	613	590	350	270	0.41
SV-49	48448	29.92	7.88	396	370	230	120	0.14
SV-50/51	57822	27.14	7.72	512	485	315	170	0.03
SV-52	20328	29.09	7.95	433	400	260	110	0.95
SV-53	57824	25.96	7.63	506	480	280	170	0.13
SV-55	57863	24.79	7.79	501	450	300	140	36
SV-56	57864	25.32	7.58	2310	2200	1800	1100	7.0
SV-57/58	57865	29.97	8.29	464	450	290	72	0.39
SV-60/61	57956	42.42	7.80	1830	1700	1100	130	0.09
SV-62	57957	23.89	7.16	1192	1100	750	390	0.17
SV-63	57958	21.23	6.79	2940	2800	2200	1200	0.15
SV-64	57959	21.45	6.95	2090	1900	1400	640	0.10
SV-65	57960	21.82	7.00	2560	2400	1900	980	0.32
SV-67	57961	20.55	7.26	1550	1400	1000	460	0.10

bold = parameter level exceeds Primary or Secondary MCL

Appendix A. Groundwater Quality Data, SVGB, 1999--Continued

Site #	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Bicarbonate (mg/l)	Chloride (mg/l)	Sulfate (mg/l)
SV-40	420	250	470	21	400	940	1300
SV-41	160	98	150	5.8	390	120	600
SV-42	110	26	150	3.2	370	110	200
SV-43	88	37	84	1.1	410	45	140
SV-44/45	37	12	39	11	160	31.5	44.5
SV-46	79	16	92	2.1	270	98	88
SV-48	74	14	48	1.4	270	37	43
SV-49	34	7.1	44	2.2	150	17	15
SV-50/51	39.5	15	44	4.7	160	47	44.5
SV-52	30	8	53	4.4	160	20	40
SV-53	45	11	43	3.1	150	48	40
SV-55	35	13	44	15	220	33	14
SV-56	280	84	180	7.2	170	200	920
SV-57/58	16.5	7.55	78	5.95	170	29	37
SV-60/61	45.5	1.6	350	6.65	100	430	110
SV-62	99	34	130	2.5	450	87	160
SV-63	310	110	210	5.4	280	490	660
SV-64	180	47	220	2.6	400	360	210
SV-65	260	87	220	4.5	270	350	600
SV-67	120	42	170	1.6	480	150	220

bold = parameter level exceeds Primary or Secondary MCL

Appendix A. Groundwater Quality Data, SVGB, 1999--Continued

Site #	Nitrate-Nitrite-N (mg/l)	Nitrate - N (mg/l)	Nitrite-N (mg/l)	TKN (mg/l)	Ammonia-N (mg/l)	Phosphorus (mg/l)
SV-40	6.0	6.0	ND	0.31	ND	ND
SV-41	ND	ND	ND	ND	ND	ND
SV-42	0.14	0.14	ND	ND	ND	ND
SV-43	ND	ND	ND	0.23	ND	0.097
SV-44/45	2.3	2.3	ND	ND	ND	ND
SV-46	0.35	0.35	ND	ND	ND	ND
SV-48	0.027	0.027	ND	0.15	ND	ND
SV-49	7.5	7.5	ND	ND	ND	ND
SV-50/51	2.6	2.6	ND	0.066	ND	ND
SV-52	4.4	4.4	ND	0.11	ND	ND
SV-53	1.8	1.8	ND	ND	ND	ND
SV-55	ND	ND	ND	3.5	1.7	0.20
SV-56	1.6	1.6	ND	0.33	ND	0.021
SV-57/58	3.55	3.55	ND	0.69	ND	ND
SV-60/61	1.85	1.85	ND	0.59	ND	ND
SV-62	0.049	0.049	ND	ND	ND	ND
SV-63	18	17.97	0.03	0.37	ND	ND
SV-64	15	15	ND	0.24	ND	ND
SV-65	19	19	ND	0.33	ND	0.06
SV-67	7.4	7.4	ND	0.2	ND	0.021

bold = parameter level exceeds Primary or Secondary MCL

ND = Not detected above the minimum reporting level

Appendix A. Groundwater Quality Data, SVGB, 1999–Continued

Site #	Aluminum (mg/l)	Antimony (mg/l)	Arsenic (mg/l)	Barium (mg/l)	Beryllium (mg/l)	Boron (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Copper (mg/l)
SV-40	ND	ND	0.016	ND	ND	0.84	ND	ND	0.014
SV-41	ND	ND	ND	ND	ND	0.2	ND	ND	ND
SV-42	ND	ND	ND	ND	ND	0.18	ND	ND	ND
SV-43	ND	ND	ND	ND	ND	0.11	ND	ND	0.031
SV-44/45	ND	ND	ND	ND	ND	0.14	ND	0.014	ND
SV-46	ND	ND	ND	ND	ND	0.18	ND	ND	ND
SV-48	ND	ND	ND	ND	ND	ND	ND	ND	ND
SV-49	ND	ND	ND	ND	ND	0.12	ND	ND	ND
SV-50/51	ND	ND	ND	ND	ND	0.13	ND	0.032	ND
SV-52	ND	ND	ND	ND	ND	0.17	ND	ND	ND
SV-53	ND	ND	ND	ND	ND	ND	ND	ND	ND
SV-55	ND	ND	ND	ND	ND	0.2	ND	ND	ND
SV-56	ND	0.0054	ND	ND	ND	ND	ND	ND	ND
SV-57/58	ND	ND	ND	ND	ND	0.22	ND	0.042	ND
SV-60/61	ND	ND	0.021	ND	ND	0.775	ND	0.013	ND
SV-62	ND	ND	ND	ND	ND	0.22	ND	ND	ND
SV-63	ND	0.0067	ND	ND	0.00052	0.29	ND	ND	ND
SV-64	ND	0.0050	ND	ND	ND	0.35	ND	ND	ND
SV-65	ND	0.0068	0.014	ND	ND	0.38	ND	ND	ND
SV-67	ND	ND	0.011	ND	ND	0.32	ND	ND	ND

bold = parameter level exceeds Primary or Secondary MCL

ND = Not detected above the minimum reporting level

Appendix A. Groundwater Quality Data, SVGB, 1999--Continued

Site #	Fluoride (mg/l)	Iron (mg/l)	Lead (mg/l)	Manganese (mg/l)	Mercury (mg/l)	Selenium (mg/l)	Silver (mg/l)	Thallium (mg/l)	Zinc (mg/l)
SV-40	2.3	0.17	ND	ND	ND	ND	0.012	ND	0.23
SV-41	2.8	1.6	ND	0.064	ND	ND	ND	ND	0.25
SV-42	4.0	ND	ND	ND	ND	ND	ND	ND	0.2
SV-43	3.0	ND	ND	ND	ND	ND	ND	ND	ND
SV-44/45	0.6	ND	ND	ND	ND	ND	ND	ND	ND
SV-46	3.6	ND	ND	ND	ND	ND	ND	ND	0.64
SV-48	3.1	ND	ND	ND	ND	ND	ND	ND	ND
SV-49	0.87	ND	ND	ND	ND	ND	ND	ND	0.22
SV-50/51	0.865	ND	ND	ND	ND	ND	ND	ND	ND
SV-52	0.55	ND	ND	ND	ND	ND	ND	ND	ND
SV-53	0.87	ND	ND	ND	ND	ND	ND	ND	0.62
SV-55	0.24	ND	ND	0.18	ND	ND	ND	ND	ND
SV-56	0.81	ND	ND	ND	ND	0.015	ND	ND	ND
SV-57/58	2.5	ND	0.0059	ND	ND	ND	ND	ND	ND
SV-60/61	5.9	ND	ND	ND	ND	ND	ND	ND	ND
SV-62	1.2	ND	ND	ND	ND	ND	ND	ND	ND
SV-63	1.2	ND	ND	0.21	ND	0.011	ND	ND	ND
SV-64	1.2	ND	ND	ND	ND	0.008	ND	ND	ND
SV-65	1.2	0.70	ND	0.059	ND	0.0083	ND	ND	0.17
SV-67	1.4	ND	ND	ND	ND	0.0078	ND	ND	ND

bold = parameter level exceeds Primary or Secondary MCL

ND = Not detected above the minimum reporting level

Appendix A. Groundwater Quality Data, SVGB, 1999–Continued

Site #	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Ra-226+228 (pCi/L)	Mass Uranium (ug/l)	Perchlorate (mg/l)	d D (‰)	d ¹⁵ N (‰)	d ¹⁸ O (‰)	SDW VOCs (ug/l)
SV-39	15+/-1.3	21+/-1.8	< LLD	45+/-5.8	ND	-66.0	7.57	-9.1	ND
SV-40	50+/-1.6	34+/-3.8	< LLD	45+/-6.4	ND	-66.5	5.82	-9.0	ND
SV-41	12+/-1.2	15+/-1.4	< LLD	22/-2.4	ND	-69.0	INS	-9.1	ND
SV-42	96+/-2.6	33+/-1.4	< LLD	220+/-17	ND	-75.0	INS	-10.7	ND
SV-43	53+/-2.0	22+/-1.2	< LLD	28+/-2.4	ND	-76.5	INS	-10.8	ND
SV-44/45	2.3+/-0.61	9.7+/-0.98	-	-	ND	-82.5	3.79	-11.3	ND
SV-46	53+/-2.0	69+/-1.7	20+/-2.6	160+/-11	ND	-74.5	17.98	-10.4	ND
SV-48	93+/-2.0	49+/-1.6	< LLD	120+/-9.2	ND	-76.5	34.59	-11.0	ND
SV-49	2.4+/-0.56	3.2+/-0.86	-	-	ND	-61.0	3.52	-8.8	ND
SV-50/51	3.5+/-0.48	4.2+/-0.87	-	-	ND	-71.75	8.57	-10.1	ND
SV-52	5.0+/-0.50	5.1+/-0.90	< LLD	-	ND	-56.5	9.53	-7.7	ND
SV-53	7.6+/-0.56	5.0+/-0.92	< LLD	-	ND	-68.0	14.42	-9.6	ND
SV-55	2.3+/-0.7	18+/-1.2	-	-	ND	-66.75	23.82	-10.2	ND
SV-56	-	-	-	-	ND	-67.0	7.68	-9.1	ND
SV-57/58	8+/-0.98	7.2+/-0.96	< LLD	-	ND	-74.5	7.86	-10.3	ND
SV-60/61	6.4+/-0.66	6.9+/-1.00	< LLD	-	ND	-75.75	10.39	-10.15	ND
SV-62	200+/-2.6	93+/-2.2	< LLD	230+/-14	ND	-74.5	13.52	-10.5	ND
SV-63	1100+/-5.8	600+/-7.4	23+/-1.6	1500+/-94	ND	-74.5	11.5	-10.0	ND
SV-64	140+/-2.2	76+/-2.4	< LLD	330+/-22.0	ND	-74.5	8.48	-10.1	ND
SV-65	190+/-2.4	130+/-3.8	15+/-1.4	190+/-6.4	ND	-77.0	7.84	-10.4	ND
SV-67	160+/-2.2	74+/-2.0	< LLD	240+/-15	ND	-	-	-	ND

bold = parameter level exceeds Primary or Secondary MCL

LLD = Lower Limit of Detection

INS=Insufficient nitrogen for analysis

ND = Not detected above the minimum reporting level

Appendix B. SVGB Aquifer 95 Percent Confidence Intervals

Constituent	Alluvial Aquifer		Hardrock Aquifer	
	# of Sites	95% Confidence Interval	# of Sites	95% Confidence Interval
Physical Parameters				
Temperature (°C)	16	26.0 to 31.7	24	18.6 to 22.0
pH-field (su)	16	7.47 to 7.86	24	7.33 to 7.60
Turbidity (ntu)	16	0.80 to 1.90	24	0.15 to 6.78
General Mineral Constituents				
Alkalinity, total	16	122 to 176	24	214 to 283
SC-lab (FS/cm)	16	457 to 838	24	686 to 1141
Hardness	16	129 to 209	24	242 to 425
TDS	16	299 to 539	24	449 to 764
Major Ions				
Calcium	16	34 to 61	24	62 to 101
Magnesium	16	9 to 15	24	21 to 43
Sodium	16	39 to 124	24	57 to 111
Potassium	16	0.71 to 14.1	24	3.82 to 6.67
Bicarbonate	16	150 to 216	24	260 to 339
Chloride	16	24 to 140	24	43 to 111
Sulfate	16	36 to 64	24	58 to 18
Nutrients				
Nitrate (NO ₃ -N)	16	1.89 to 4.75	24	1.11 to 6.62
TKN	16	0.03 to 0.06	24	-0.05 to 0.54
Trace Elements				
Boron	16	0.10 to 0.31	24	0.13 to 0.26
Fluoride	16	0.98 to 2.73	24	1.03 to 2.23
Zinc	16	0.04 to 0.26	24	0.08 to 0.28
Radiochemistry Constituents				
Gross Alpha (pCi/l)	16	2.4 to 16.3	18	12.4 to 63.4
Gross Beta (pCi/l)	16	0.3 to 17.5	18	11.1 to 32.4

All units mg/l except where noted

Appendix C. SVGB Geological 95 Percent Confidence Intervals

Parameter	Granitic Rock		Metamorphic Rock		Volcanic Rock	
	# of Sites	95% CIs	# of Sites	95% CIs	# of Sites	95% CIs
Physical Parameters						
Temperature (°C)	13	16.8 to 21.7	3	13.3 to 31.1	8	17.9 to 24.9
pH-field (su)	13	7.13 to 7.43	3	7.26 to 8.01	8	7.46 to 7.93
Turbidity (ntu)	13	0.5 to 6.1	3	-39.0 to 63.4	8	-0.46 to 1.49
General Mineral Constituents						
Alkalinity, total	13	261 to 338	3	87 to 247	8	145 to 247
SC-lab (FS/cm)	13	884 to 1552	3	257 to 656	8	409 to 774
Hardness	13	270 to 574	3	18 to 309	8	173 to 332
TDS	13	575 to 1050	3	226 to 375	8	274 to 499
Major Ions						
Calcium	13	70 to 132	3	-14 to 116	8	39 to 82
Magnesium	13	21 to 59	3	4 to 17	8	15 to 39
Sodium	13	92 to 162	3	12 to 57	8	21 to 47
Potassium	13	2.7 to 6.6	3	-9.9 to 24.5	8	4.0 to 7.0
Bicarbonate	13	314 to 402	3	109 to 297	8	179 to 301
Chloride	13	50 to 167	3	15 to 40	8	16 to 74
Sulfate	13	97 to 295	3	3 to 38	8	18 to 48
Nutrients						
Nitrate (as N)	13	-0.19 to 6.04	3	-5.24 to 12.28	8	-2.25 to 13.27
TKN	13	0.07 to 0.19	3	-3.74 to 6.15	8	0.01 to 0.14
Trace Elements						
Boron	13	0.16 to 0.37	3	-0.06 to 0.32	8	0.06 to 0.16
Fluoride	13	1.69 to 3.34	3	0.05 to 0.72	8	0.31 to 0.99
Zinc	13	0.04 to 0.38	3	-0.37 to 0.70	8	-0.01 to 0.29
Radiochemistry Constituents						
Gross Alpha (pCi/l)	11	21.9 to 97.1	3	-0.05 to 3.40	4	-1.55 to 12.85
Gross Beta (pCi/l)	11	14.0 to 46.2	3	-4.18 to 26.38	4	6.52 to 7.18

All units mg/l except where noted

Appendix D. Data on Sample Sites, SVGB, 1999

Site #	Cadastral	Latitude - Longitude	ADWR #	ADEQ #	Sample Type	Well Depth	Water Depth	Aquifer	Geology
SV-01	(B-19-19)17ddd	35°01'53.891" 114°19'02.079"	517211	57599	Random	200'	45'	Hardrock	volcanic
SV-02	(B-21-19)33cbd	35°09'35.757" 114°19'16.134"	534212	57746	Random	245'	124'	Hardrock	volcanic
SV-03	(B-21-17)35bbc	35°10'08.014" 114°04'16.996"	632772	48679	Random	175'	75'	Hardrock	volcanic
SV-04/05	(B-20-16)10dbc	35°07'43.378" 113°57'27.879"	555437	57747	Random	202'	80'	Hardrock	volcanic
SV-06	(B-22-17)30ca	35°15'46.053" 114°08'27.853"	602518	57745	Random	175'	40'	Hardrock	granite
SV-07	(B-22-19)11bdd	35°18'34.743" 114°16'57.802"	506879	48705	Random	200'	60'	Hardrock	volcanic
SV-09	(B-22-20)13cbcb	35°17'48.503" 114°22'37.395"	none	21921	Random	spring	spring	Hardrock	volcanic
SV-10	(B-23-18)03add	35°25'07.703" 114°11'31.628"	508555	57744	Random	100'	30'	Hardrock	granite
SV-13	(B-20-19)09cac	35°07'40.595" 112°16'05.254"	560184	57779	Random	365'	160'	Alluvial	alluvial
SV-15	(B-21-20)02dcb	35°13'48.761" 114°22'57.467"	none	21793	Random	spring	spring	Hardrock	volcanic
SV-16	(B-20-18)23cad	35°06'12.965" 114°10'02.209"	543553	57782	Random	900'	600'	Alluvial	alluvial
SV-17/20	(B-19-17)16ac	35°01'56.483" 114°04'25.800"	805603	57781	Random	N/A	45'	Alluvial	alluvial
SV-18	(B-19-18)05bda	35°03'55.179" 114°13'12.908"	529616	57784	Random	625'	513'	Alluvial	alluvial
SV-21/22	(B-19-16)07ddc	35°02'16.378" 114°00'22.030"	638923	21387	Random	N/A	N/A	Hardrock	granite
SV-23	(B-18-17)11ccc	34°57'08.137" 114°03'12.992"	805611	57785	Random	N/A	N/A	Alluvial	alluvial
SV-24/25/26	(B-16-20)14cab	34°43'33.451" 114°25'59.761"	628108	57955	Random	396'	217'	Alluvial	alluvial
SV-27	(B-17-18)25adb	34°49'55.865" 114°08'34.050"	628123	48451	Random	800'	305'	Alluvial	alluvial
SV-28	(B-21-16)28bcd	35°10'38.430" 113°59'24.456"	528814	57954	Random	800'	580'	Hardrock	volcanic
SV-29/30	(B-18-18)20cdc	34°55'38.342" 114°13'16.936"	none	21174	Random	spring	spring	Hardrock	volcanic

Appendix D. Data on Sample Sites, SVGB, 1999–Continued

Site #	Cadastral	Latitude - Longitude	ADWR #	ADEQ #	Sample Type	Well Depth	Water Depth	Aquifer	Geology
SV-31	(B-20-17)14bcd	35°07'02.581" 114°02'59.503"	none	21572	Random	spring	spring	Hardrock	granite
SV-32	(B-18-19)09abb	34°58'00.544" 114°18'18.915"	none	57952	Random	spring	spring	Hardrock	volcanic
SV-33	(B-15-14)08adb	34°39'26.767" 113°44'27.775"	614802	57826	Random	383'	75'	Hardrock	granite
SV-34	(B-15-14)20aab	34°38'03.497" 113°44'26.727"	642277	57934	Targeted	N/A	N/A	Hardrock	granite
SV-35	(B-14-15)02aab	34°35'26.483" 113°47'41.306"	645966	57935	Random	150'	20'	Hardrock	granite
SV-36	(B-13-15)12acb	34°26'12.347" 113°50'07.678"	645970	57936	Random	20'	16'	Hardrock	volcanic
SV-37	(B-13-16)26dbc	34°26'05.015" 113°54'14.937"	645969	57937	Random	100'	50'	Hardrock	metamorphic
SV-38	(B-14-15)13dda	34°32'58.946" 113°46'29.437"	645965	57942	Targeted	150'	20'	Hardrock	granite
SV-39	(B-15-15)15bcb	34°38'37.824" 113°49'31.242"	645967	57943	Random	300'	50'	Hardrock	granite
SV-40	(B-15-15)15bcb	34°38'36.689" 113°49'30.570"	645968	57944	Targeted	140'	80'	Hardrock	granite
SV-41	(B-16-15)36dbc	34°40'59.143" 113°46'47.038"	614815	57945	Random	145'	75'	Hardrock	granite
SV-42	(B-17-16)02bbc	34°53'14.792" 113°56'38.956"	none	57946	Random	spring	spring	Hardrock	granite
SV-43	(B-18-16)26acc	34°54'49.909" 113°56'27.582"	none	57947	Random	spring	spring	Hardrock	granite
SV-44/45	(B-21-18)32bbb	35°10'08.512" 114°14'03.048"	623083	57948	Random	1355'	820'	Alluvial	alluvial
SV-46	(B-15-16)01cab	34°40'05.766" 113°53'26.851"	none	57949	Random	N/A	N/A	Alluvial	alluvial
SV-48	(B-16-16)14bcb	34°43'47.861" 113°54'43.950"	618231	57820	Random	275'	N/A	Hardrock	granite
SV-49	(B-17-17)31dbb	34°48'39.230" 114°06'58.653"	601492	48448	Random	450'	400'	Alluvial	alluvial
SV-50/51	(B-16-19)01cac	34°45'13.633" 114°12'20.631"	543918	57822	Random	185'	100'	Alluvial	alluvial
SV-52	(B-15-19)07aab	34°39'39.828" 114°17'04.022"	629451	20328	Random	900'	473'	Alluvial	alluvial

Appendix D. Data on Sample Sites, SVGB, 1999–Continued

Sample #	Cadastral	Latitude - Longitude	ADWR #	ADEQ #	Sample Type	Well Depth	Water Depth	Aquifer	Geology
SV-53	(B-16.5-18)27aba	34°47'33.998" 114°07'46.651"	543765	57824	Random	465'	380'	Alluvial	alluvial
SV-55	(B-15-18)30dda	34°36'34.144" 114°10'44.003"	803930	57863	Random	205'	90'	Hardrock	metamorphic
SV-56	(B-15-18)30	34°37'01.084" 114°10'53.481"	803931	57864	Targeted	> 250'	> 250'	Hardrock	metamorphic
SV-57/58	(B-14-17)12baa	34°34'26.344" 113°59'35.053"	539067	57865	Random	807'	675'	Alluvial	alluvial
SV-60/61	(B-16-21)36cbb	34°43'33.717" 114°27'48.053"	531890	57956	Random	720'	174'	Alluvial	alluvial
SV-62	(B-24-18)33bba	35°25'55.607" 114°12'49.468"	801522	57957	Random	50'	35'	Hardrock	granite
SV-63	(B-23-18)03bbb	35°24'56.292" 114°11'43.413"	510970	57958	Targeted	120'	35'	Hardrock	granite
SV-64	(B-23-18)03bba	35°25'04.229" 114°11'38.743"	514003	57959	Targeted	140'	30'	Hardrock	granite
SV-65	(B-23-18)03bdc	35°24'54.411" 114°11'41.115"	531300	57960	Targeted	300'	57'	Hardrock	granite
SV-67	(B-23-18)03bcb	35°24'53.158" 114°12'00.443"	801415	57961	Targeted	120'	20'	Hardrock	granite

Appendix E. Volatile Organic Compounds (VOCs) Analyte List

Benzene	1,2-Dichloroethene	1,1,2-Trichloroethane
Bromozone	1,1-Dichloroethene	Trichloroethene
Bromochloromethane	cis-1,2-Dichloroethene	Trichlorofluoromethane
Bromodichloromethane	trans-1,2-Dichloroethene	1,2,3-Trichloropropane
Bromoform	1,2-Dichloropropane	1,2,4-Trimethylbenzene
Bromomethane	1,3-Dichloropropane	1,3,5-Trimethylbenzene
n-Butylbenzene	2,2-Dichloropropane	Vinyl Chloride
sec-Butylbenzene	1,1-Dichloropropene	Total Xylenes
tert-Butylbenzene	c-1,3-Dichloropropene	Methyl-t-butyl ether (MTBE)
Carbon Tetrachloride	t-1,3-Dichloropropene	
Chlorobenzene	Ethylbenzene	
Chloroethane	Hexachlorobutadiene	
Chloroform	Isopropylbenzene	
Chloromethane	p-Isopropyltoluene	
2-Chlorotoluene	Methylene Chloride	
4-Chlorotoluene	Naphthalene	
Dibromochloromethane	n-Propylbenzene	
1,2-Dibromo-3-chloropropane	Styrene	
1,2-Dibromoethane	1,1,1,2-Tetrachloroethane	
Dibromomethane	1,1,2,2-Tetrachloroethane	
1,2-Dichlorobenzene	Tetrachloroethene	
1,3-Dichlorobenzene	Toluene	
1,4-Dichlorobenzene	1,2,3-Trichlorobenzene	
Dichlorodifluoromethane	1,2,4-Trichlorobenzene	
1,1-Dichloroethane	1,1,1-Trichlorobenzene	

Source: USEPA 502.2 Safe Drinking Water List (31).

Appendix F. METHODS OF INVESTIGATION

Groundwater sites in the SVGB were sampled by the ADEQ Groundwater Monitoring Program to characterize regional groundwater quality. All samples were analyzed for Safe Drinking Water (SDW) inorganics (physical parameters, major ions, nutrients, and trace elements), SDW Volatile Organic Compounds (VOCs), perchlorate, and isotopes of hydrogen, oxygen, and nitrogen. At most sites, additional samples were collected for SDW radiochemistry analysis. No bacterial sampling was conducted since microbiological contamination problems in groundwater are often transient and subject to a variety of changing environmental conditions including soil moisture content and temperature (16).

Sampling Strategy

This study focused on groundwater quality conditions that are large in scale and persistent in time. This research is designed to identify regional degradation of groundwater quality such as occurs from non-point sources of pollution or a high density of point sources. The quantitative estimation of regional groundwater quality conditions requires the selection of sampling sites that follow scientific principles for probability sampling. Thus, sampling in the SVGB conducted by ADEQ follows a systematic grid-based, random site-selection approach. This is an efficient method because it requires sampling relatively few wells to make valid statistical statements about the conditions of large areas. This systematic element requires that the selected wells be spatially distributed while the random element ensures that every well within the grid has an equal chance of being sampled. This strategy also reduces the possibility of biased well selection and assures adequate spatial coverage throughout the study area. The main benefit of a statistically-designed sampling plan is that it allows for many more groundwater quality assumptions than would be allowable with a non-statistical approach.

The U.S. Public Land Survey System was used as a grid overlay to subdivide the SVGB into six square mile townships. Within each township, a well from the ADWR database was randomly selected to sample. Wells pumping groundwater for a variety of purposes - domestic, stock, public supply, and mining - were sampled for this study, provided each individual well met ADEQ sampling requirements. A well was considered suitable for sampling if the well owner gave permission to sample, if a sampling point existed near the wellhead, and if the well casing and surface seal appeared to be intact and undamaged. Other factors such as casing access to determine groundwater depth and construction information were preferred but not considered essential. If no registered wells were available within a township, springs or unregistered wells were randomly selected for sampling. Springs were considered adequate for sampling if they had a constant flow through a clearly-defined point of egress, and if the sample point had minimal surface impacts. Well information compiled from the ADWR well registry and spring characteristics are provided in **Appendix D**.

Several factors were considered to determine the number of sites to sample for this study. Aside from administrative limitations on funding and personnel, this decision was based on three factors related to the conditions in the area (19):

- < Amount of groundwater quality data already available.
- < Extent to which impacted groundwater is known or believed likely to occur.
- < Hydrologic complexity and variability of the area.

Previous groundwater quality studies have been conducted in the SVGB; however, no data is available for large areas of the basin. Results from these studies were used to quantify the variability of seven constituents in order to help gauge the number of sites to be sampled for the ADEQ study. Variability was calculated using the following formula: $n = 4s^2/L^2$ where n = the number of sites to sample, s is the standard deviation, and L is the allowable error, which in this study is 30 percent of the mean for each constituent (34). Of the seven constituents examined, the number of sites necessary to meet the 30 percent acceptable error limit - or to have a 95 percent chance that sample readings will fall within 70 percent of the constituent mean - ranged from 8 for total alkalinity to 48 for sulfate. As a result of this analysis based on historical groundwater quality data, 40 sites was deemed a logical size for the SVGB study. This amount exceeds the number, 30, which is typically large enough for a normally-distributed population to be recognized as such (1).

Sample Collection

The personnel who designed the SVGB study were also responsible for the collection and interpretation of the data, as recommended by hydrology sources (11). This protocol helps ensure that consistently high quality data are collected, from which are drawn relevant and meaningful interpretations. The sample collection methods for this study conformed to the *Quality Assurance Project Plan (QAPP)* (5) and the *Field Manual For Water Quality Sampling* (7). While these sources should be consulted as references to specific sampling questions, a brief synopsis of the procedures involved in collecting a groundwater sample for this study is provided.

After obtaining permission from the owner to sample the well, the water level was measured with a sounder if the casing had access for a probe. The volume of water needed to purge the well three bore hole volumes was calculated from well log and on-site information. Physical parameters - temperature, pH, and electrical conductivity - were monitored at least every five minutes using a Hydrolab multi-parameter instrument. Typically, after three bore volumes had been pumped and the physical parameters were stabilized within 10 percent, a sample representative of the aquifer was collected from a point as close to the wellhead as possible. In certain instances, it was not possible to purge three bore volumes. In these cases, at least one bore volume was evacuated and the physical parameters had stabilized within 10 percent.

Sample bottles were filled in the following order:

1. SDW VOCs;
2. Perchlorate;
3. SDW Inorganic Constituents;
4. Isotopes of Hydrogen, Oxygen, and Nitrogen; and
5. SDW Radiochemistry Constituents.

VOC samples were collected in two, 40-ml amber glass vials which contained 10 drops 1:1 hydrochloric (HCl) acid preservative prepared by the laboratory. Before sealing the vials with Teflon caps, pH test strips were used to confirm the pH of the sample was below 2 su; additional HCl acid was added if necessary. VOC samples were also checked to make sure there was no air contained in the vials. Perchlorate samples were collected in unpreserved, 500 ml plastic containers.

The inorganic constituents were collected in three, 1 liter polyethylene bottles:

- < Dissolved metal constituents were filtered into bottles preserved with 5 ml nitric acid (70 percent). Filtering was conducted using an on-site positive pressure apparatus with a 0.45 micron (μm) pore size groundwater capsule filter.
- < Nutrient constituents were collected in bottles preserved with 2 ml sulfuric acid (95.5 percent).
- < Other constituents were collected in unpreserved bottles.

Oxygen and nitrogen isotope samples were collected in 1 liter unpreserved plastic bottles; hydrogen isotope samples were collected in 500 ml unpreserved plastic bottles. All isotope bottles were filled until no headspace remained. Radiochemistry samples were collected in two collapsible 1-liter plastic containers and preserved with 5 ml nitric acid to reduce the pH below 2.5 su. With the exception of the radiochemistry, hydrogen isotope, and oxygen isotope samples, all samples were kept at 4 degrees Celsius in an ice-filled, insulated cooler. Chain of custody procedures were followed in sample handling. Groundwater samples for this study were collected between December 1998 to July 1999.

Laboratory Methods

Analyses for inorganic constituents and VOC compounds were conducted by the ADHS Laboratory in Phoenix, the only exception being one inorganic split analyzed by Bolin Laboratory in Phoenix. A complete listing of inorganic parameters, including ADHS laboratory method, USEPA water method, and Minimum Reporting Level (MRL), are provided in **Table 4**. During sample collection, temperature, pH, and SC were recorded in the field. Perchlorate samples were analyzed by Weck Laboratory in City of Industry, CA. Hydrogen and oxygen isotope samples were analyzed by the University of Arizona in Tucson, while nitrogen isotope samples were analyzed by the University of Illinois in Urbana. Two hydrogen and oxygen isotope splits were analyzed by the Stable Isotopes Laboratory at Arizona State University in Phoenix. The SDW radiochemistry samples were analyzed by the Arizona Radiation Regulatory Agency laboratory in Phoenix. The analysis of radiochemistry samples was treated according to the following SDW protocols (4): gross alpha and gross beta were analyzed, and if the gross alpha concentrations exceeded 5 pCi/l, then Radium-226 was measured. When radium-226 exceeded 3 pCi/l, radium-228 was measured. If gross alpha concentrations exceeded 15 pCi/l, then radium-226/228 and mass uranium were measured.

Appendix G. DATA EVALUATION

Quality Assurance

Quality-assurance (QA) procedures were followed and quality-control (QC) samples were collected to quantify data bias and variability for the SVGB study. The design of the QA/QC plan was based on recommendations included in the *Quality Assurance Project Plan (QAPP)* (5) and the *Field Manual For Water Quality Sampling* (7). For this study, 14 QC inorganic samples were collected: 7 duplicate samples, 1 split sample, and 6 equipment blank samples. Seven duplicate samples were also collected for VOC, perchlorate, and isotope samples; no equipment blanks were collected, however, and two split samples were collected for isotope samples. In addition, three duplicate radiochemistry samples were collected for QA/QC purposes. Based on the QA/QC results which follow, sampling procedures and laboratory equipment did not significantly affect the groundwater quality samples of this study.

Table 4. ADHS Laboratory Methods Used for the SVGB Study

Constituent	ADHS Method	Water Method	Minimum Reporting Level (MRL)
Physical Parameters			
Alkalinity	Electrometric Titration	SM232OB	2.0
SC (FS/cm)	Electrometric	EPA 120.1	1.0
Hardness	Titrimetric, EDTA	EPA 130.2	10.0
pH (su)	Electrometric	EPA 150.1	0.1
TDS	Gravimetric	EPA 160.1	10.0
Turbidity (ntu)	Nephelometric	EPA 180.1	0.01
Major Ions			
Calcium	ICP-AES	EPA 200.7	1.0
Magnesium	ICP-AES	EPA 200.7	1.0
Sodium	ICP-AES	EPA 200.7	5.0
Potassium	Flame AA	EPA 258.1	0.5
Chloride	Potentiometric Titration	SM 4500 CL D	1.0
Sulfate	Colorimetric	EPA 375.2	10.0
Nutrient Constituents			
Nitrate (as nitrogen)	Colorimetric	EPA 353.2	0.10
Nitrite (as nitrogen)	Colorimetric	EPA 353.2	0.10
Ammonia	Colorimetric	EPA 350.1	0.10
TKN	Colorimetric	EPA 351.2	0.05
Total Phosphorus	Colorimetric	EPA 365.4	0.10

All units are mg/l except as noted (28)

Table 4. ADHS Laboratory Methods Used for the SVGB--Continued

Constituent	ADHS Method	Water Method	Minimum Reporting Level (MRL)
Trace Elements			
Aluminum	ICP-AES	EPA 200.7	0.50
Antimony	Graphite Furnace AA	EPA 200.9	0.005
Arsenic	Graphite Furnace AA	EPA 200.9	0.01
Barium	ICP-AES	EPA 200.7	0.1
Beryllium	Graphite Furnace AA	EPA 200.9	0.0005
Boron	ICP-AES	EPA 200.7	0.10
Cadmium	Graphite Furnace AA	EPA 200.9	0.0010
Chromium	Graphite Furnace AA	EPA 200.9	0.010
Copper	Graphite Furnace AA	EPA 200.9	0.010
Fluoride	Ion Selective Electrode	SM 4500 F-C	0.20
Iron	ICP-AES	EPA 200.7	0.10
Lead	Graphite Furnace AA	EPA 200.9	0.005
Manganese	ICP-AES	EPA 200.7	0.05
Mercury	Cold Vapor AA	SM 3112 B	0.0005
Selenium	Graphite Furnace AA	EPA 200.9	0.005
Silver	Graphite Furnace AA	EPA 200.9	0.001
Thallium	Graphite Furnace AA	EPA 200.9	0.005
Zinc	ICP-AES	EPA 200.7	0.05

All units are mg/l (28)

Equipment Blanks - Equipment blanks were collected to ensure adequate decontamination of sampling equipment and that the filter apparatus and/or deionized water supplied by the ADHS laboratory were not impacting the groundwater quality sampling. Equipment blank samples for major ion and nutrient analyses were collected by filling unpreserved and sulfuric acid-preserved bottles with deionized water. Equipment blank samples for trace parameter analyses were collected with deionized water that had been filtered into nitric acid preserved bottles. Locations of the equipment blank samples are provided in **Figure 5**.

Systematic contamination was judged to occur if more than 50 percent of the equipment blank samples contained measurable quantities of a particular groundwater quality constituent. SC and turbidity were detected in all six equipment blanks, while hardness was detected in five equipment blanks. As such, SC, hardness, and turbidity were considered to be affected by systematic contamination; however, the extent of contamination was not considered significant. This conclusion was reached in the following manner:

- < SC had a mean concentration of 2.97 FS/cm in the equipment blanks; this was less than 1 percent of the SC median concentration for the study. The SC detections in the blanks may be explained in two ways: water passed through a deionizing exchange unit will normally have an SC value of at least 1 FS/cm while carbon dioxide from the air can dissolve in deionized water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity (19).
- < Turbidity had a mean concentration of 0.12 ntu in the equipment blanks; this was less than 1 percent of the turbidity median concentration for the study. Testing indicates turbidity is present at 0.01 ntu in the deionized water supplied by the ADHS laboratory, and concentrations increase with time due to storage in ADEQ carboys (28).
- < Hardness had a mean concentration of 12.3 mg/l in the equipment blanks, less than 5 percent of the median hardness concentration for the study. Hardness detections appear to occur from inadequate decontamination of the transfer vessels as extensive testing by the ADHS laboratory of deionized water and groundwater filters revealed no hardness detections (28).

Calcium, total alkalinity, and bicarbonate also had detections in equipment blanks, though in less than 50 percent of the cases. Overall, the effects of sampling equipment and procedures on the groundwater quality samples are not considered significant for the purposes of this study.

Duplicate Samples - Duplicate samples are identical sets of samples collected simultaneously from one source and submitted to the same laboratory. Data from duplicate samples provide a measure of variability from the combined effects of field and intra-laboratory procedures. Duplicate samples were collected from sampling sites that were believed to have elevated constituent concentrations as judged by field SC values. Locations of the duplicate samples are provided in **Figure 5**. Variability in constituent concentrations between each pair of duplicate samples is provided both in terms of absolute levels and as the percent difference. Percent difference is defined as the absolute difference between levels in the duplicate samples divided by the average level for the duplicate samples, multiplied by 100 (**Table 5**). Only constituents having levels exceeding the Minimum Reporting Level (MRL) were used in this analysis. The results indicate that of the 20 constituents examined, the maximum duplicate difference rarely exceeded 10 percent while the median differences - except for turbidity (22 percent) and TKN (42 percent) - were within 3 percent. Turbidity values can be impacted by the exceedance of this parameter's holding time (28); this occurred frequently due to turbidity's short holding time. TKN differences might be related to the analysis

Table 5. Summary Results of SVGB Duplicate Samples from ADHS Laboratory

Constituent	Number	Difference in Percent			Difference in Levels		
		Minimum	Maximum	Median	Minimum	Maximum	Median
Physical Parameters							
Alkalinity, Total	7	0	0.02	0	0	2	0
SC (FS/cm)	7	0	0.04	0	0	20	0
Hardness	7	0	0.09	0	0	10	0
pH-field (su)	7	0	0.07	0.01	0	0.05	0.01
TDS	7	0	0.07	0.03	0	20	10
Turbidity (ntu)	7	0	147	0.22	0	3.22	0.2
Major Ions							
Bicarbonate	7	0	0	0	0	0	0
Calcium	7	0	0.18	0.02	0	3.0	1.0
Magnesium	7	0	0.07	0	0	0.5	0
Sodium	7	0	0.03	0	0	2.0	0
Potassium	7	0	0.02	0	0	0.1	0
Chloride	7	0	0.03	0	0	10.0	0
Sulfate	7	0	0.03	0	0	2.0	1.0
Nutrients							
Nitrate (as N)	7	0	0.09	0	0	0.03	0
TKN	5	0.11	0.70	0.42	0.006	0.062	0.029
Trace Elements							
Boron	6	0	0.16	0	0	0.03	0
Chromium	3	0	0.05	0	0	0.002	0
Copper	2	0	0.32	--	0	0.008	--
Fluoride	7	0	0.03	0	0	0.1	0
Zinc	2	0	0.10	0	0	0.009	0

All units are mg/l except as noted with certain physical parameters

of this parameter, which is particularly difficult and sensitive (28). Based on these results, the differences in parameter levels of duplicate samples were not considered to significantly impact the groundwater quality data for inorganic constituents. However, perchlorate analytical results in this study are suspect because at two sites where duplicate samples were collected (SV-17/20 and SV-24/25), perchlorate was detected in one sample while the duplicate had no detection of this compound.

Split Samples - Split samples are identical sets of samples collected simultaneously from one source that are submitted to separate laboratories to check for inter-laboratory differences. A single inorganic split sample was collected from a well in the Hualapai Mountains (**Figure 5**). Analytical results from the split sample were evaluated by examining the variability in constituent concentrations in terms of absolute levels and as the percent difference. Of the constituent concentrations exceeding MRLs, all had less than 10 percent difference with the exception of TDS (19 percent) and TKN (34 percent). Based on these results, the differences in parameter levels of split samples were not considered to significantly impact the groundwater quality data.

Standard Reference Samples - During sampling in the Upper San Pedro groundwater basin in 1996-1997 by the ADEQ Groundwater Monitoring Unit in conjunction with the USGS National Water-Quality Assessment Program, standard reference samples were submitted to the ADHS laboratory for analysis. The standard reference samples for general mineral constituents, major ions, nutrients, and trace elements were created by the USGS Branch of Quality Systems. Data from these samples provide a measure of the bias of the ADHS laboratory. Results from this earlier study identified a high bias of the fluoride, magnesium, and zinc analyses from the ADHS laboratory (10). The bias in the levels of these parameters was considered in the interpretation of data for groundwater quality samples in the SVGB.

Data Validation

The analytical work for this study was subjected to the following six different QA/QC correlations:

Cation/Anion Balances - Cation/anion balance is an analysis such that, if found to be within acceptable limits, it can be assumed there are no important errors in concentrations reported for major ions (19). Cation/anion balances were all within acceptable limits (90 - 110 percent) with the exception of two samples, SV-01 (111 percent) and SV-37 (116 percent), which barely exceeded the acceptable limits. Laboratory personnel indicated that other parameters not tested for, such as bromide and iodine, could have affected these two cation/anion balances (28). Overall, cation/anion balances of SVGB groundwater samples were significantly correlated at $p \leq 0.01$.

SC/TDS - The SC and TDS levels measured by contract laboratories were significantly correlated at $p = 0.01$. Similarly, field-SC and TDS levels were significantly correlated at $p \leq 0.01$. Typically, the TDS value in mg/l should be from 0.55 to 0.75 times the SC in FS/cm for groundwater up to several thousand mg/l (18). Groundwater high in bicarbonate and chloride will have a factor near the lower end of this range; in contrast, groundwater high in sulfate may reach or even exceed the upper end (19). The relationship of TDS to SC becomes indefinite for groundwater with both very high and low concentrations of dissolved solids (19). The overall lab SC - TDS variation for the study was within 1 percent.

Hardness - The levels of laboratory-measured hardness concentrations were significantly correlated ($p \leq 0.01$) with calculated hardness concentrations. Hardness was calculated using the following formula:

$[(\text{calcium in mg/l} \times 2.497) + (\text{magnesium in mg/l} \times 4.118)]$. The overall hardness variation for the study was within 1 percent.

SC - The SC measured in the field using a Hydrolab at the time of sampling was significantly correlated at $p \leq 0.01$ with the SC measured by contract laboratories. The overall field/lab SC variation for the study was within 8 percent.

pH - The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage (19). Thus, the pH values measured in the field using a Hydrolab at the time of sampling were not significantly ($p \leq 0.05$) correlated with the pH values determined by the laboratories.

Groundwater Temperature/Groundwater Depth - Groundwater temperature measured in the field was compared to groundwater depth to examine the relationship that exists between temperature and depth. Groundwater temperature should increase with depth, approximately 3 degrees Celsius with every 100 meters or 328 feet (8). Groundwater temperature and groundwater depth were significantly correlated at the $p \leq 0.01$ level.

The analytical work conducted for this study was considered valid based on the 14 quality control samples and the 6 QA/QC correlations.

Statistical Considerations

Various methods were used to complete the statistical analyses for the groundwater quality data of this study. All statistical tests were conducted on a personal computer using SYSTAT software. Initially, data were tested for both non-transformed and log-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option (9). Results of this test using non-transformed data revealed that of 21 constituents, only bicarbonate, pH-field, temperature, and zinc were normally distributed. The distribution of many groundwater quality parameters is often not Gaussian or normal, but skewed to the right. The results of the log-transformed test revealed that 16 of the 21 log-transformed parameters were normally-distributed. In summary, non-transformed data of SVGB parameters are overwhelmingly not normally-distributed while roughly three-quarters of the log-transformed parameters are normally-distributed. The most recent and comprehensive statistical references specifically recommend the use of non-parametric tests when the non-normality assumption is violated (17). Thus, various aspects of the SVGB groundwater quality were analyzed using the following statistical methods:

Spatial Relationships: The non-parametric Kruskal-Wallis test was applied to investigate the hypothesis that levels of constituents from groundwater samples in different groundwater aquifers, geologic types, and/or sub-basins in the SVGB, were the same. The Kruskal-Wallis test uses the differences but also incorporates information about the magnitude of each difference. The null hypothesis of identical median values for all data sets within each test was rejected if the probability of obtaining identical medians by chance was less than $p = 0.05$. For geologic comparisons of four factors, if the null hypothesis was rejected for any of the tests conducted, the Tukey method of multiple comparisons on the ranks of the data was applied. The Tukey test identified significant differences between constituent concentrations when compared to each possibility within each of the four tests (17). Both the Kruskal-Wallis and Tukey tests are not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL (17). Consequently, the Kruskal-Wallis test was not calculated for trace elements such as antimony, arsenic,

barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, as well as phenolphthalein alkalinity, nitrite, ammonia, and total phosphorus. Highlights of these statistical tests are summarized in the groundwater sampling results section.

Groundwater Level Relationships: Simple regression was used to examine relationships between constituent concentrations and groundwater depth. Groundwater depth was determined using a sounder in the field when possible or obtained from well driller's logs. Comparisons were conducted using three distinct methods:

<	Linear Model	$[P] = md + b$	$[P]$ vs d
<	Exponential Model	$[P]_d = [P]_{d=0}e^{-rd}$	$\ln[P]$ vs d
<	Biphasic Model	$[P] = a(d)^{-b}$	$\ln[P]$ vs $\ln d$

The null hypothesis of no association between variables was rejected if the probability of obtaining the correlation by chance was less than or equal to 0.05. Significant correlations between the data sets are summarized in the groundwater sampling results section.

Correlation Between Parameter Levels: In order to assess the strength of association between levels of various groundwater quality constituents, concentrations were compared to each other using the Pearson Correlation Coefficient test. The Pearson Correlation Coefficient varies between -1 and +1, with a value of +1 indicating that a variable can be predicted perfectly by a positive linear function of the other, and vice versa. A value of -1 indicates a perfect inverse or negative relationship. The results of the Pearson Correlation Coefficient analysis were then subjected to a probability test to determine which of the individual pair-wise correlations were significant. The Pearson Correlation Coefficient test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL. Consequently, Pearson Correlation Coefficients were not calculated for trace parameters such as antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, as well as phenolphthalein alkalinity, nitrite, ammonia, and total phosphorus (17). Significant highlights from this statistical test are summarized in the groundwater sampling results section.

Time-Trend Analysis: Changes in groundwater quality constituent concentrations over time were examined utilizing data collected from the same wells by the USGS in 1979, ADWR in 1990, and ADEQ in 1999. The Wilcoxon rank-sum statistic, which is a non-parametric measure of association between two independent sets of data, was used to test the null hypothesis that constituent concentrations collected in 1979 were the same as those collected during 1990 and 1999. The null hypothesis of identical median values for all three data sets was rejected if the probability of obtaining identical medians by chance was less than 0.05. The Wilcoxon test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL (17). Consequently, the Wilcoxon test was not calculated for trace constituents such as antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, as well as phenolphthalein alkalinity, nitrite, ammonia, and total phosphorus. Highlights from these statistical tests are summarized in the groundwater sampling results section.